Sources of Variation in Voluntary Feed Intake and Nutrient Utilization for Milk Production of Dairy Cows

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ABSTRACT

The influence of animal characteristics immediately post-partum on the voluntary feed intake and nutrient utilization for milk production during 24 weeks of lactation was studied in two trials, one involving cows and the other cows plus heifers. The influence of eating behaviour on daytime voluntary feed intake was studied in early lactation (weeks 1-8) using 33 animals and in middle and late lactation with 40 animals.

It was shown that environmental factors (years and months of calving), parity, calving liveweight, calving condition score, milk yield in lactation week 2 and liveweight change within the period of lactation explained the following proportion of the variation in voluntary feed intake 41.3-60.1 and 48.0-74.9%; in milk yield 23.3-58.9 and 33.3-91.5%; in energy balance 30.1-69.0 and 28.6-50.6%; gross efficiency 25.5-69.0 and 35.5-62.2%; in net efficiency 27.5-68.0 and 32.6-42.9% and in nitrogen efficiency 19.3-48.1 and 20.8-58.9% for different stages of lactation in Trials 1 and 2 respectively.

In the behaviour study the animals were found to have a two-peak pattern of eating; the hour immediately after fresh feed offering and milking. Fifty per cent of the within day variation between animals in voluntary feed intake was due to differences in the time spent eating.

The selection of animals for high milk yields has resulted in animals with high appetites and efficiency, and the ability to mobilize body reserves in early lactation. Animal to animal variation in the mobilization and storage of body reserves was the main cause of differences between animals in energetic and nitrogen efficiency for milk production. Calving condition score was not related to voluntary feed intake or to nutrient utilization after lactation week 12; and milk yield. It was concluded that calving condition score can be manipulated to improve voluntary feed intake without affecting milk yield. Areas of further research are suggested.

DECLARATION

I declare that this thesis is my own composition, and does not include work submitted for any other degree or professional qualification. The thesis reports my analysis of data on eating behaviour collected by myself and data on feed intake and milk production available at the Edinburgh School of Agriculture.

CONTENTS

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GLOSSARY

The following abbreviations of statistical conventions and technical terms are used.

STATISTICAL CONVENTIONS	ABBREVIATIONS
Not significant	NS
Significant at 5% level of probability	*
Significant at 1% level of probability	**
Significant at 0.1% level of probability	***
Standard error	SE
Coefficient of variation	CV
Proportion of variation accounted for by regression	R^2
Residual standard deviation	RSD
Standard deviation	SD
Variance	σ^2

TECHNICAL TERMS	
Dry matter	DM
Dry matter intake	DMI
Dry matter intake as % of liveweight	DMI%
Dry matter intake per liveweight$^{0.75}$	DMI/W$^{0.75}$
Metabolizable energy	ME
Metabolizable energy concentration in the dry matter	M/D
Calving condition score	CS
Body condition score	BS
Liveweight	LW
Liveweight change	LWC
Body condition score change	BSC
Backfat area	BFA
Backfat area change	BFAC
Volatile fatty acids	VFA
Digestibility of the organic matter	OMD
Digestibility of organic matter in dry matter	DOMD
Efficiency of utilization of ME for body gain	K_g
Efficiency of utilization of ME for milk production	K_l
Efficiency of utilization of ME for maintenance	K_m
Agricultural Research Council	ARC
Ministry of Agriculture, Fisheries and Food	MAFF
National Research Council	NRC

I INTRODUCTION

Feed intake is a major determinant of animal performance and efficiency (Balch, 1976). Recent reviews (Balch and Campling, 1969; Bines, 1976, 1979; Journet and Remond, 1976) have indicated that voluntary feed intake of dairy cattle is an important part of a complex process of energy balance within the animal's body. The factors which influence intake are numerous and complex and include feed, animal, environmental and managerial factors. The majority of experiments have tended to concentrate on feed and managerial factors with few experiments designed to study the influence of animal factors.

There is now a need to quantify the degree to which the animal itself influences feed intake. This is because in the past few years remarkable progress has been made, through both genetic selection and improved management and nutrition, in increasing milk yield. The ability of the manager to control feed intake of dairy cattle has declined due to a change from individual to group feeding systems. Also little concomitant effort has been extended to establish if genetic improvement alters nutrient requirements. The need for further information on voluntary feed intake has therefore become critical for the correct use of present recommended dietary requirements for dairy cattle at various physiological stages and particularly for the high producing heifer which is still growing.

Several researchers have attempted to predict appetite of dairy cows in the United Kingdom (Curran, Wimble and Holmes, 1970; Bines et al, 1977; Vadiveloo and Holmes, 1979; ARC, 1980; Lewis, 1981). These were based on data from cows of average to low milk production potential (16.2 to 26.8 kg/day). The accuracy of these equations in predicting intake in high

yielding cows is poor to moderate (Neal, Thomas and Cobby, 1984). The use of these equations for high yielding dairy cows can lead to serious errors in feed formulation as actual intake will be over or underpredicted.

The main characteristics of the dairy cow identified as influencing feed intake are: live bodyweight, milk yield, milk quality, stage of lactation, parity or age, pregnancy, body fatness and probably feeding behaviour (Bines, 1976, 1979). These same factors are acknowledged to influence feed utilization; animals consuming the most feed tend to be the most efficient converters of feed to animal products (Blaxter, 1962). This is because a fixed maintenance requirement has to be satisfied before nutrients are made available for production.

Whereas most of these animal factors are easy to measure accurately, body fatness has remained difficult to quantify. Thus information regarding its influence on feed intake and feed utilization for milk production is conflicting (Bines, 1979; Broster and Broster, 1984). These differences are partly due to confusion in the terminology used by different researchers for assessing body fatness, which is difficult to measure in the live animal. Yet there is the suspicion that body fatness, as a source of body reserves, could be the most important factor interacting with feed intake especially in early lactation for the high yielding dairy cow to express its potential (Bines and Hart, 1982). The lack of a scale to quantify this has prevented the proper investigation of this hypothesis.

Recently, however, body condition scoring of cattle was developed (Lowman, Scott and Sommerville, 1976). This is a subjective measure of assessing the level of body fatness by estimating the degree of fat cover over the transverse processes of the 4th and 5th lumbar vertebrae and around the

tail head. Its relationship with actual body composition of dairy cattle needs quantification to improve its usefulness. Ultrasonic measurements of the body is another method which has been used successfully to evaluate fat and lean tissues; these measurements correlate well with in vivo body fat (Simm, 1983b). This is a useful tool for studying the influence of body fatness on input-output relationships of dairy cows.

Bodyweight change, traditionally used for assessing body reserve change and food utilization has been criticised because its interpretation in relation to body fat and body protein is difficult (Moe, Tyrrel and Flatt, 1971). There is also doubt about the amount of bodyweight change due to gut fill. In experiments lasting over 6 weeks frequent weighing is reported to smooth out fluctuations in gut fill (Broster, 1974). There is therefore a need to identify an adequate measure of body fatness and body fat change in order to quantify relationships with feed intake and milk production. A combination of body condition score and bodyweight change needs to be studied as an alternative to each separately.

The characteristics of the animal are difficult to control and, in feed intake experiments, attempts at this tend to fall short of intended levels (eg Garnsworthy and Topps, 1982b). Valuable information can, however, be obtained using data collected from sizeable cow groups (Wood, 1975).

The control of feed intake by either physical or physiological regulation by the dairy cow can be both on a long-term or short-term basis (Baumgardt, 1970). Long-term regulation may be due to a homeostatic mechanism. On a daily basis, however, regulation of intake can be associated with eating behaviour. By varying the size, duration and number of meals an animal can adjust daily feed intake (Bines, 1976). Information on the role of eating behaviour on the voluntary feed intake of the housed dairy cow is limited

(Campling and Morgan, 1981). Information on feeding behaviour is of potential value in the manipulation of voluntary feed intake of housed dairy cows and can also provide useful information in the design of facilities for group feeding.

In 1979 the Edinburgh School of Agriculture initiated a research programme designed to investigate the input-output relationships of high yielding dairy cows and heifers. Specific objectives of the programme were to provide information on:

(1) nutrient intake and utilization by high yielding dairy cows;

(2) the interacting factors influencing this so that feed intake could be predicted or modified more accurately;

(3) the interaction of body reserves and feed intake on input-output relationships.

The work described in this thesis was undertaken to:

(1) study some of the animal factors influencing voluntary intake and nutrient utilization for milk production;

(2) study the relationship of voluntary feed intake and eating behaviour of lactating housed dairy cattle in early, middle and late lactation.

1 REVIEW OF THE LITERATURE

1.1 Factors Affecting Voluntary Feed Intake of Dairy Cattle

1.1.1 INTRODUCTION

Several reviews over the past two decades have analysed the factors influencing regulation of feed intake by ruminants (Balch and Campling, 1969; Baumgardt, 1970; Campling, 1970) and others have described the mechanisms involved (Baile and Mayer, 1970; Jones, 1972; Baile and Forbes, 1974; Baile, 1975; Bines, 1976, 1979; Journet and Remond, 1976; Campling, 1980; Broster, Sutton and Bines, 1982). A consensus of opinion from these and older reviews is that animals adjust voluntary feed intake to meet their energy requirements (Baile and Forbes, 1974). So over longer periods of time the adult animal can keep energy intake in balance with energy output, if the amount of feed consumed and its energy content are not limiting factors (Baumgardt, 1970).

The hypothalamus plays an important role in the central control of feed intake (Balch and Campling, 1969; Baile and Forbes, 1974). The origin of feedback signals to this central control system which determine feed intake have been identified as stimuli arising from the process of absorbing and metabolising nutrients from ingested food, known as metabolic control, and stimuli arising from distension of the alimentary tract by physical presence of food, known as physical control (Baile and Mayer, 1970; Campling, 1970; Forbes, 1980). Several complex interacting factors of dietary and of animal origin play important roles in these systems of feed regulation (Wangsness and Muller, 1981). Important dietary factors include diet composition, digestibility and

physical structure. Animal factors include body size, milk yield, parity or age, stage of lactation, body condition and pregnancy. Management factors such as type of feeding system (group or individual feeding) and feeding frequency and environmental factors such as temperature, humidity and daylength also affect voluntary feed intake (Bines, 1979; NRC, 1981; Forbes, 1982).

Comprehensive reviews on the metabolic control (Baile and Mayer, 1970; Baumgardt, 1970; Jones, 1972; Baile and Forbes, 1974; Forbes, 1980) and the physical control (Balch and Campling, 1969; Campling, 1970; Vansoest, 1975) of feed intake are available. Also similar reviews on the influence of dietary, environmental and management factors on feed intake are available (Bines, 1976, 1979; Journet and Remond, 1976; Kaufman, 1976; NRC, 1981; Forbes, 1982; Broster et al, 1982). Therefore, only animal factors influencing voluntary intake are reviewed in detail in this thesis.

Several mechanisms have been classified as being involved in the metabolic control of feed intake. These have been identified as chemostatic, thermostatic and lipostatic mechanisms (Baile and Forbes, 1974).

1.1.2 REGULATION OF FEED INTAKE

1.1.2.1 Metabolic Control

The short-term regulation of feed intake is thought to be caused by chemostatic mechanisms (Baile and Forbes, 1974; Baile and Della-Ferra, 1981). The absorption of nutrients from the gastrointestinal tract and their levels in the blood is thought to send feedback signals to the satiety centre of the hypothalamus. A number of blood and

gastrointestinal tract metabolites, glucose, free fatty acids, vitamins, minerals and volatile fatty acids have been suggested as possible determinants of this (Baile and Forbes, 1974; Forbes, 1980). Of these glucose has received the most attention due to it being recognised as part of the control mechanism of feeding in non-ruminants. In ruminants, however, it is unlikely that glucose is the satiety signal for blood glucose levels as anterio-venous difference is very small in ruminants (Baile and Mayer, 1970).

Negative correlations between free fatty acids and dry matter intake have been observed in dairy cattle, leading to the suggestion that concentrations of free fatty acids may act as a signal to decrease feeding (Journet and Remond, 1976; Garnsworthy and Topps, 1982a). Also intraduodenal injection of long chain fatty acids was noted to depress feed intake (Baile and Mayer, 1970). Whether the depression was due to rumino-reticulum movements or to a change in blood fat levels was not clear.

High levels of volatile fatty acids (VFA) are known to depress feed intake. Acetate has been identified as the primary depressant of feed intake among the VFA (Baile and Mayer, 1970; Jones, 1972; Baile and Forbes, 1974) though both propionate and butyrate have depressing effects on food intake. Forbes (1980) speculated that propionate probably plays a similar role in the control of feed intake in ruminants as glucose in non-ruminants. This might explain why feeds containing high propionate levels or feeds producing high propionate in the rumen are associated with reduced feed intake.

It is not known if hormones influence feed intake. Concentrations

of glucagon, prolactin and insulin increase during feeding whereas growth hormone decreases during feeding in ruminants (Forbes, 1980). Blood insulin levels in dairy cows are positively related to dry matter intake and have curves similar to dry matter intake during lactation (Garnsworthy and Topps, 1982a).

Peptides such as cholecystokinin, bombesin and pancreatic polypeptide found in the gastrointestinal tract are thought to influence feed intake. Only cholecystokinin has so far been shown to play a role in the control of feed intake in ruminants (Baile and Della-Ferra, 1981).

Thermostatic regulation of feed intake under normal physiological conditions in ruminants has not been demonstrated (Balch and Campling, 1969). Changes in environmental temperature may, however, influence feed intake. In cold environments feed intake of ruminants is observed to increase whereas in warm or hot environments the reverse is the case (Bines, 1976; NRC, 1981).

The theory of lipostatic regulation of feed intake is an attempt to explain the remarkable ability that ruminant animals have of apparent striving to maintain a relatively constant body weight or body fatness in the face of various stresses; nutritional, physiological and environmental in nature (Journet and Remond, 1976). The importance of lipostatic control for long-term regulation of energy balance is indicated by the negative correlation between body fat and feed intake observed in dairy cattle (Grainger et al, 1982; Garnsworthy and Topps, 1982b).

Feedback mechanisms noted in the literature for lipostatic control of feed intake are:

(1) direct effect of free fatty acids on the hypothalamus (Journet and Remond, 1976);

(2) hormones may serve as messengers between fat depots and the hypothalamus (Baile and Forbes, 1974);

(3) the size of adipocytes may initiate control signals to the hypothalamus (Baumgardt, 1970).

Evidence for these mechanisms still needs to be found.

The lipostatic theory is incompatable with fattening in farm animals (Blaxter, 1962). It also fails to explain the low intake in early lactation when body tissues are being mobilized to satisfy nutrient requirements or in late lactation when body reserves are being deposited for subsequent lactation. It can be argued though that neither the dairy cow nor the fattened animal reach a constant bodyweight before the fat stored is used in lactation or the animal slaughtered.

1.1.2.2 Physical Control

Depending on the chemical and physical composition of a diet, intake is controlled either by physical factors such as rumen capacity, distension, digestibility or the rate of removal of digesta (Campling, 1970).

The relationship between feed intake and rate of disappearance of digesta is reflected in the relationship between voluntary feed intake and digestibility of forages. Rate of disappearance of digesta from the reticulo-rumen depends on the rate at which food is broken down chemically by the processes of digestion and the rate at which undigested residues are broken down physically before they can be removed from the rumen (Balch and Campling, 1969; Campling, 1970).

The positive relationship between digestibility and feed intake observed is dependent on the type of forage, type of conservation or processing and physiological state of the animal (Wilkins, 1974; Vansoest, 1975; Bertilsson and Burstedt, 1983). With high roughage diets of low digestibility (less than 67%) regulation of intake is by the physical limitations of the gut but for high digestible feeds (greater than 67%) chemostatic factors come into play (Conrad et al, 1964).

1.1.3 FACTORS OF ANIMAL ORIGIN

Aforementioned factors of dietary, environmental, managerial and of animal origin interact to influence potential feed intake of the dairy cow. Only the animal factors are reviewed here.

Several animal factors have been reported to influence voluntary feed intake in the dairy cow. These are:

(1) body weight or size;

(2) lactation (milk yield);

(3) age;

(4) pregnancy;

(5) body condition;

(6) stress and disease;

(7) probably feeding behaviour (Broster et al, 1982; Weston, 1982).

1.1.3.1 Bodyweight, Size and Age

Bodyweight, size and age will be reviewed together due to the high correlation between size and age within the same breed (Johnson et al, 1966).

The measurement of size on a weight scale can be misleading as it

conceals variations in the linear dimensions of an animal and its degree of fatness (Bines, 1976). The feed intake of a thin cow and a fat cow of similar recorded weights may therefore be different. Big cows are normally expected to have higher feed intake capacity than small cows (Donker, Marx and Young, 1983) because of a larger reticulo-rumen (Nutt et al, 1980). This is thought to be of less importance with highly digestible diets (Bines, 1979).

Different estimates of the exponent relating feed intake to liveweight are reported in the literature. Brody (1945) reasoned that maximal relative food capacity was related approximately to basal metabolism and showed that the exponent 0.73 was the most appropriate factor relating basal metabolism to liveweight of mature animals in several species. Kleiber (1932) provided evidence to show that the relationship between basal metabolism and weight for separate groups of animals could best be represented by $W^{0.75}$. This was internationally accepted (Kleiber, 1965).

The exponent relating feed intake to liveweight can be derived by regressing the logarithm of intake on the logarithm of liveweight. When this is applied to stall fed and grazing dairy cows the exponent is variable. Conrad et al (1964) observed that, for diets with digestibility coefficients between 52 to 66%, intake was related to weight raised to power one whilst for diets of higher digestibility the relationship was the power 0.73 in dairy cattle. Curran et al (1970), on the other hand, found that neither the power 1.00, 0.66 nor 0.73 fitted their data. The range of liveweights (coefficient of variation = 10-12%) was too small in this experiment to produce significant differences between the animals in voluntary feed intake. Yadava et al (1970)

and Yungblut et al (1981) reported voluntary feed intake to be proportional to weight raised to the power 1.00 and 0.73 respectively. Differences between animals in milk yield were, however, not accounted for in the data of Yadava et al (1970). Johnson et al (1966) cautioned against predicting forage intake using bodyweight from mature dairy cattle of the same breed as they found no relationship between forage intake and size during the lactation period ($r = 0.06$).

Broster et al (1980) explained the reported differences in these exponents as being due to different experimental diets causing gut fill and hence liveweight variations. There therefore seems to be no advantage to using other exponents except one to relate feed intake to liveweight within the same breed of dairy cattle (Weston, 1982).

Miller et al (1973); Grieve et al (1976) and Korver (1982) found that the correlation coefficients between liveweight and feed intake decreased as lactation increased and ranged from 0.15 to 0.36 (see Table 1.1). Liveweight has an important effect on total feed intake but this is influenced by diet quality. Voluntary feed intake varied from 1 kg DM per 100 kg liveweight with mixed diets of hay and grass silage to 1.4-1.6 kg DM per 100 kg liveweight (LW) with grass silage and 2 kg DM/100 kg LW with mature maize silage (Journet and Remond, 1976), or 1.07 kg DM/100 kg LW for complete diets (forage plus concentrate) (Brown et al, 1977).

Feed intake increases with the age of the animal (Erb et al, 1982). Heifers eat less than older cows and this difference can be as much as 36% (Bines et al, 1977). Heifers were observed to eat slightly more feed, when intake was expressed as per cent of liveweight, than cows

Table 1.1 Correlation coefficients between dry matter intake and lactation traits

TRAITS	PERIOD OF LACTATION (DAYS)				SOURCE
	1-90	**91-180**	**181-305**	**Total**	
		DRY MATTER INTAKE			
Body weight post-partum	0.28	0.28	0.15	0.27	Grieve et al (1976)
Body weight loss[b]	- 0.28	0.29	0.16	0.10	
Body weight end of lactation	0.17	-0.10	-0.12	-0.04	
305-day SCM[a] yield	0.31	0.78	0.82	0.81	
		WEEKS			
	1-13	**14-30**	**31-42**		
Liveweight	0.31 to 0.36	0.25 to 0.30	0.21 to 0.22		Miller et al (1973)
FCM[c]	0.15 to 0.50	0.57 to 0.70	0.70 to 0.73		
		EFFICIENCY			
Dry matter intake	-0.38 to-0.24	-0.09 to 0.24	0.30 to 0.42		Miller et al (1973)
Liveweight	-0.29 to-0.13	-0.42 to-0.34	-0.48 to-0.45		
FPCM[d]	0.52 to 0.82	0.69 to 0.98	0.70 to 0.97	0.69 to 0.95	Kover (1982)
Energy intake	-0.05 to-0.33	-0.04 to 0.50	-0.14 to 0.50	0.11 to 0.32	
Liveweight change	-0.31 to-0.79	-0.12 to-0.54	-0.10 to-0.80	-0.31 to-0.71	
Liveweight	0.69 to 0.95	0.11 to 0.32	-0.31 to-0.71	0.13 to-0.85	
FCM[c]	0.78 to 0.85	0.77 to 0.82	0.82 to 0.98		

[a] SCM = Solids corrected milk

[b] Body weight loss post-partum to peak lactation

[c] FCM = Fat corrected milk

[d] FPCM = Fat protein corrected milk

(Ostergaard, 1979) but not in all experiments (Donker et al, 1983). When feed intake is expressed per unit of metabolic body size it was similar between cows and heifers (Cowan et al, 1981; Strickland and Broster, 1981; Brow, Tyrrel and Williams, 1983). Other reports failed to show such similarities (Donker et al, 1983). Cows, however, consume less feed intake in the first few days post-calving than heifers and have a lower rate of rumen contractions for the first 7 days post-calving (Marquadt, Horst and Jorgensen, 1977).

There is a greater lag between peak voluntary intake and milk yield in heifers than cows due to a delayed peak intake and an earlier peak yield (Bines, 1976; Ostergaard, 1979).

The relation of feed intake to liveweight is also influenced by the breed of the cow. Brigstocke et al (1982) observed that Jersey cows peaking at 27.8 kg/day milk in week 7 of lactation were eating daily 45.6 g/kg LW whereas Neilson et al (1983) noted that Friesian cows peaking at about 38.0, 34.0 and 28.0 kday milk ate 31.0, 29.0 and 28.0 g/kg LW respectively from week 1-26 of lactation.

Negative correlation coefficients between body weight change and feed intake have been observed with forage diets (Johnson et al, 1966) but only in early lactation (days 1 to 90) with normal dairy diets of forage and concentrate (Grieve et al, 1976). Journet and Remond (1976) noted that intakes were high as long as cows lost body weight and were in negative energy balance. The use of liveweight change as a factor affecting feed intake, especially in prediction equations, must be used with caution; liveweight change is useful in describing low intakes in early lactation and high intakes in late lactation (Bines,

1979).

1.1.3.2 Lactation

Lactating dairy cows increase their feed intake in response to the demands of milk synthesis; this is acknowledged to lag several weeks behind peak milk yield (Balch and Campling, 1969; Bines, 1979).

Lactating cows also eat more than non-lactating controls. This has been shown by comparisons of monozygotic twins fed fresh grass indoors (Hutton, 1963) or fed hay or concentrates (Campling, 1966).

The relationship between voluntary feed intake and milk yield is such that it is unclear as to which is the dependent and which is the independent variable. Do high producing cows give more milk because they have a greater feed intake or do they have a greater feed intake because their body metabolism is supporting a greater rate of milk synthesis? As explained by Monteiro (1972), if milk yield was dependent on feed intake, the controlling system would be of an open loop type, where the production at any moment is a function of the food entering the system. However, if the stimulus to produce comes prior to any change in feed intake a closed-loop mechanism will be involved. In this case milk output would itself emit a feedback signal so that feed intake could be changed accordingly. Liveweight changes are more likely to be influenced by the former case than is milk yield, where onset of lactation is determined by the birth of a calf, which can hardly be attributed to changes in food intake.

Work from New Zealand (A M Bryant, Personal Communications) indicate that cows eat more because they produce more. This is evidenced by the high correlation between milk yield and udder volume

immediately after milking. In other words, cows with large udders produce more milk. And differences between cows in udder volume is present at calving; most udder growth occurring during the latter part of pregnancy. After calving the udder regresses at a similar rate between high and low yielding cows. Thus the suggestion is that mammary tissue sets the level of yield and therefore feed intake.

It appears that adaptation in feed intake is one important component in the regulation of nutrient partitioning occurring in an integrated manner with the alteration in other processes during early lactation. An important point is the low correlations between FCM and DM intake in early lactation which increases with advancing lactation (Hooven et al, 1972; Grieve et al, 1976).

Increased voluntary feed intake due to lactation is influenced by the type of diet fed (Ronning and Laben, 1966; Bines et al, 1977; Broster et al, 1982; also Table 1.2). High correlations, therefore, between milk yield and voluntary feed intake seem to occur in cases where concentrates are rationed according to milk yield (Campling, 1966). Significant correlations between milk yield and feed intake have been observed in experiments where concentrate was not allocated according to milk yield (Curran et al, 1970).

Theoretical coefficients relating milk yield to voluntary feed intake is about 0.4 kg DM/kg FCM for a diet of metabolizability (q) of 0.7. However, when concentrate and forage ratios are maintained constant the partial regression coefficients are about 0.09 to 0.14 kg DM/kg FCM (Bines, 1979). For diets with q = 0.53 regression coefficients were 0.13 kg DM/kg FCM (Conrad et al, 1964). Osbourn (1980) noted

Table 1.2 Peak milk yield and peak dry matter intake in cows and heifers given ad libitum access to rations of hay and concentrate (Bines, 1976)

	% concentrate in the ration		
	60	**75**	**90**
Peak yield (kg/day)			
Heifers	21.4	25.8	23.8
Cows	29.7	30.3	36.1
Time of peak yield (week)			
Heifers	7.0	7.7	7.5
Cows	5.0	7.0	9.9
Peak intake (kg/day)			
Heifers	18.4	18.1	19.1
Cows	21.0	20.4	22.8
Time of peak intake (week)			
Heifers	15.7	17.9	13.7
Cows	11.7	10.0	12.8
Milk fat (%)[a]			
Heifers	3.2	2.8	2.8
Cows	3.0	2.8	2.5

[a] Mean of weeks 1-18

that partial regression coefficient relating appetite to FCM was 0.13 kg DM/kg FCM on good quality diets and 0.36 kg DM/kg FCM for complete diets.

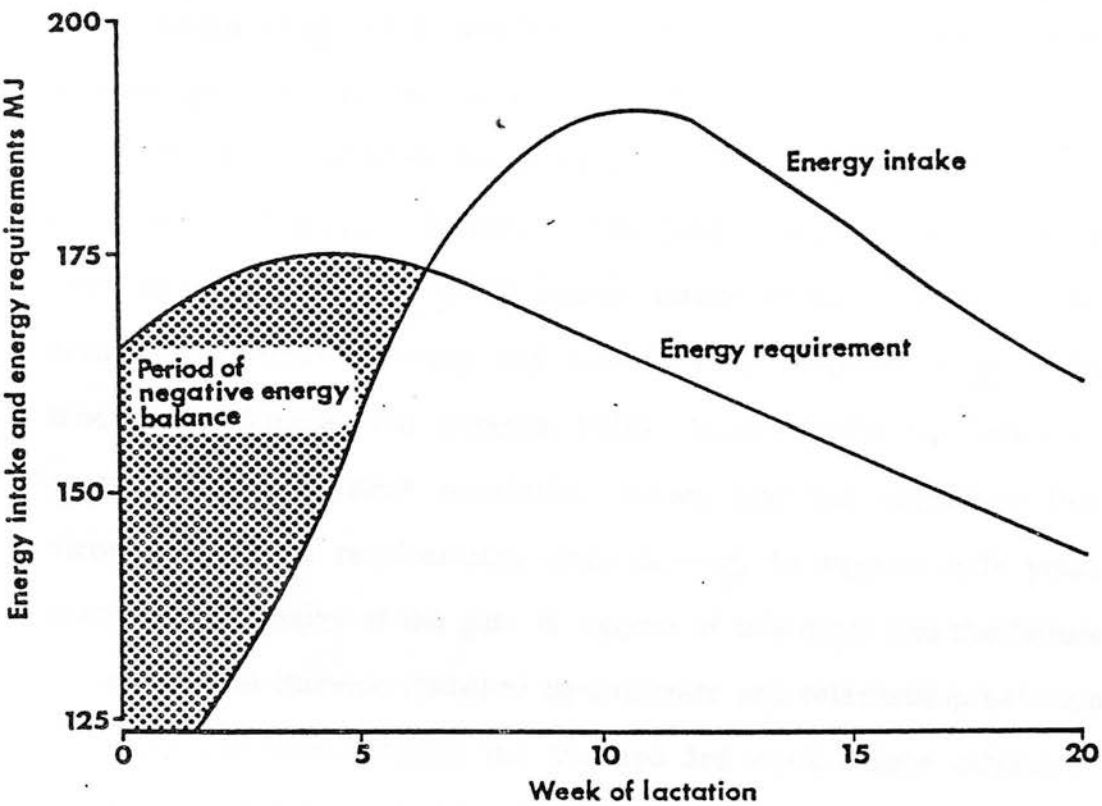
Milk yield rises quickly after calving, reaching a peak between 35 to 50 days of lactation and thereafter declines at a variable rate per week (about 2.5%) until end of lactation (Bines, 1976; Journet and Remond, 1976; Brown et al, 1977; Broster et al, 1982). Appetite, on the other hand, increases more slowly after calving and reaches a peak several weeks after peak yield (Balch and Campling, 1969; Ostergaard, 1979). This is discussed and illustrated by Neilson (1982, Figure 1.1). It appears that the lag between peak milk yield and peak food intake is greater in the first than in subsequent lactations (Bines, 1976). In early lactation daily DM intake may amount to only 1.5% of liveweight and at peak, 12-15 weeks pre-partum, reach a level of 3.6% of liveweight, with an average of 3% over 1 to 18 weeks of lactation (Broster and Alderman, 1977).

The lag between peak yield and peak intake can be reduced by management and level of nutrition before and after calving (Bines, 1976, 1979; Broster et al, 1982; Kunz et al, 1985). With complete diets, Coppock et al (1974) observed that feed intake peaked in 14 weeks on diets containing 75% roughage but 6 weeks for diets containing only 30% roughage. Most reports indicate early peaking for cows fed diets of high digestibility or higher energy than diets of low digestibility and low energy content. Week of peak lactation was, however, different between experiments (Steen and Gordon, 1980a; Steen and Gordon, 1980b; Krohn et al, 1983 and Table 1.2).

Figure 1.1

A TYPICAL PATTERN OF ENERGY INTAKE AND ENERGY REQUIREMENTS FOR AN AVERAGE BRITISH FRIESIAN *

(Neilson, 1982)



*Based on the Scottish Milk Records Association 1981 305 day lactation yield for British Friesians excluding heifers 5672 kg

Why feed intake lags behind milk yield in early lactation is not known. It has been suggested (Bines, 1976; Journet and Remond, 1976; Ellis, 1978) that the lag may be caused by physical control of intake due to the time it takes for (1) body fat in the abdominal cavity to be used up and the uterus to involute, and (2) the gastrointestinal tract to hypertrophy to increased demands for nutrients. There are conflicting reports in the literature in support of these suggestions. Forbes (1970) found a correlation between hay intake and compressible abdominal contents when twin bearing ewes were compared to single bearing ones. Lodge et al (1975) pointed out that feed intakes were higher in cows given a low level of feeding before parturition, thus calving in a thin state, than those which were well fed in late pregnancy. The involvement of physical factors in low feed intake in early lactation seem to be supported by the increased intake of high digestible diets during this period (Ronning and Laben, 1966; Coppock et al, 1974; Bines, 1976; Journet and Remond, 1976). Forbes (1977) has, however, questioned the physical restriction theory and has suggested that increased nutrient requirements after calving, to support milk yield, result in hypertrophy of the gut. In support of this query was the failure by Journet and Remond (1976) to demonstrate any relationship between voluntary DM intake during the 2nd and 3rd week before calving to weight of conception products in dairy cows. However, Hartnell and Satter (1979) noted a 10 kg increase in total ingesta between weeks 0-12 and 13-24 of lactation. On average, total rumen contents were closely related to dry matter intake. It is not clear if thin cows which do not mobilize body fat have a lag between feed intake and feed requirements. The influence of both physical restriction and gut hypertrophy acting together on feed intake is therefore possible.

Journet and Remond (1976) have put forward the following interpretation of increased feed intake and changes occurring after calving:

(1) Deficiency of nutrients for milk synthesis and mobilization of lipids are stimuli for the feeding control centre. The latter modifies the feeding behaviour of the animal by increasing the length or rate of eating resulting in increased feed intake.

(2) Progressive hypertrophy and hyperplasia result in increased absorption of end products of digestion.

The lag between peak milk yield and peak voluntary feed intake could also be considered as part of homeostatic and homeorhetic mechanisms (Bauman and Currie, 1980) in which the cow has this preference to use body reserves instead of eating.

After peak lactation, a cow on adequate rations is now able to meet her energy requirements. And later in lactation when feed intake exceeds requirements the cow is able to replace previously mobilized body tissues (Bines, 1976). Dry matter intake decreased by 1 kg from 160-200 days post-partum and, again, by about 2 kg from 200-300 days post-partum when cows were fed 70% concentrate diet (Brown et al, 1977). Appetite does not decrease much until the animal either becomes too fat, lactation is terminated or the animal becomes heavily pregnant (Broster et al, 1982).

1.1.3.3 Pregnancy

With advancing gestation there is an increase in the volume and nutrient demand of the conceptus with a concomitant change in the dam's endocrine status (Weston, 1982). These changes have been noted to affect voluntary feed intake (Forbes, 1970, 1971). Forbes (1970) has

recorded increased feed intake in early and mid-pregnancy of sheep. It is not clear if this response was the result of increased nutrient requirements which occur at this time. The situation in dairy cattle is made complicated by the confounding effect of both pregnancy and milk production at this time.

Feed intake declines in the last 6 weeks of pregnancy and the rate of decline is influenced by the metabolizability of the diet (Journet and Remond, 1976). The upward displacement of the ventral sac of the rumen in late pregnancy has been shown to be associated with a reduction in rumen digesta volume and voluntary intake (Forbes, 1970). Abdominal wall distension and pressure on the rumen may also affect voluntary intake (Forbes, 1980). Forbes (1969) suggested that the growth of the uterus may cause a reduction in the volume of the rumen and its contents. Forbes (1969) has further demonstrated an inverse relationship, in sheep, between the volume of rumen contents and the volume of compressible abdominal contents (uterus + abdominal fat + empty digestive tract + liver + spleen + kidney).

These results may not relate to dairy cattle which have less abdominal fat and produce in most cases one foetus. Lambeth (1969) found no significant difference between pregnant and non-pregnant heifers in rumen contents. This is in agreement with reports by Hartnell and Satter (1979) who found no significant difference between rumen contents in Holsteins at 8, 5, 2 or 1 week before calving.

Increased secretions of oestrogen by extra ovarian tissues (placenta) in conjunction with progesterone have been suggested as the probable cause of voluntary feed intake depression in late pregnant sheep (Forbes,

1970). Increased oestradiol levels probably reduce the sheep's capacity to use energy (Weston, 1982).

1.1.3.4 Body Condition

There are conflicting reports on the ability of the dairy cow to vary its feed intake to compensate for changes in energy and environmental conditions to maintain a consistent body size or fat content (Forbes, 1977).

Fat cows ate 31% less hay and 23% less hay plus concentrate than thin cows; these differences increased to 76 and 52% respectively when feed intake was related to metabolic body size (Bines et al, 1969). Fat ewes also ate 26% less grass than ewes with less than 10% body fat (Foot, 1972).

During lactation voluntary feed intake tends to be inversely related to body fat content (Grainger et al, 1982). Lodge et al (1975) observed that during lactation dairy cows of higher body fat content at calving were associated with 6% lower voluntary intake in early lactation. Foot and Russel (1979) and Cowan et al (1980) noted that lactating ewes in different fat conditions show 5 to 15% lower voluntary feed intake in fatter animals, which was not related to the diet on offer.

Reports (Yadava et al, 1970; and others, see Table 1.3) indicate higher intakes by cows of lower condition score as compared with cows of higher condition. Grainger et al (1982) noted the following inverse relationship between voluntary intake and calving condition score in dairy cows stall-fed pasture: DM intake (kg/day) = 17.0 - 1.0 ($\pm$0.4) condition score. The influence of body condition on feed intake was only significant between weeks 1 and 8 of lactation in this report.

Table 1.3 Effect of body condition score on voluntary feed intake, milk yield, milk composition and energetic efficiency

TRAIT	CONDITION SCORE (1-5 units)			SOURCE
	1.5 - 2.0	2.5 - 3.0	3.5 - 4.0	
Dry matter intake (kg/day)	19.4	17.8		[a]Land and Leaver (1980)
Peak milk yield (kg/day)	31.7	36.7		
Average milk yield (kg/day)	27.5	30.0		
Milk fat (g/kg)	39.8	40.1		
Milk protein (g/kg)	32.8	30.7		
Liveweight change (kg/day)	0.19	-0.02		
Cows				
Dry matter intake (kg/day)		16.3	15.9	[b]Land and Leaver (1980)
Milk yield (kg/day)		23.6	25.7	
Milk fat (g/kg)		38.6	39.5	
Milk protein (g/kg)		31.9	30.6	
Condition score change		-0.41	-1.03	
Liveweight change (kg/day)		-0.04	-0.10	
305-day milk yield		5096	7518	
Heifers				
Milk yield (kg/day)		17.7	21.2	
Milk fat (g/kg)		39.7	41.5	
Milk protein (g/kg)		34.4	33.6	
Condition score change		-0.33	-0.96	
Liveweight change (kg/day)		0.43	0.16	
305-day milk yield (kg)		4736	5518	
Dry matter intake (kg/day)	19.5	18.2	16.2	[c]Garnsworthy and Topps (1982)
Maximum peak intake (kg DM/day)	22.2 to 22.5	21.0 to 21.4	20.3 to 21.0	
Week of peak intake	7.9 to 9.3	9.6 to 12.7	14.1 to 14.5**	
Milk fat content (g/kg)	36.5 to 39.2	36.1 to 40.5	38.1 to 40.9	
Gross efficiency (%)	34.7	35.2 to 35.7	37.4 to 38.8	

Continued/...

Table 1.3 continued

TRAIT	CONDITION SCORE (1-5 units)			SOURCE
	3.38	**3.73**	**3.99**	
Dry matter intake (kg/day)	18.0	18.0	18.0	[d]Boisclair et al (1984)
Milk yield (kg/d)	31.0	32.6	32.1	
Milk fat (g/kg)	33.4	29.2	36.3	
Milk protein (g/kg)	31.7	30.8	31.0	
	2.0	**3.5**		
Dry matter intake (kg/day)	18.8	17.4*		[e]Garnsworthy and and Gardner (1985)
Milk yield (kg/day)	26.6	27.6		
Milk fat (g/kg)	48.5	50.4		
Milk protein (g/kg)	34.6	33.8		
Condition score change	0.5	-1.0***		
Liveweight change (kg/day)	3.9	-27.7**		
	2.0	**3.0**		
Dry matter intake (kg/day)	19.4	17.8		[f]Roberts and Ferns (1984)
Milk fat (g/kg)	39.8	40.1		
Milk protein (g/kg)	32.8	30.7		
Milk yield (kg/day)	27.5	30.0		

Duration of experiments (weeks)

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

a 16
b cows 16
heifers 8
c 16
d 12
e 20
f 16

Contrary to these reports, other experiments, in which some cows were fed at higher level of nutrition to calve in fatter condition than those fed at low level, showed no influence of body condition on feed intake (Daveport and Rakes, 1969; Fronk et al, 1980). The range of condition scores were, however, small in some of these experiments to result in any significant differences between cows. Even so, thin cows ate more food than fat cows.

The cause of the inverse relationship between body fat and feed intake is thought to be associated with reduced gastrointestinal digesta load of fat cows (Bines et al, 1969; Cowan et al, 1980). This has resulted in the suggestion that abdominal fat physically reduces potential rumen capacity and therefore feed intake.

The involvement of metabolites in feedback regulation between body fat and the satiety centre has been suggested (Forbes, 1980). With increasing size of adipocytes, as an animal grows fat, there is probably an impairment or a reduction in the capacity of the adipocytes to synthesise more triglycerides. Thus fatty acids released during triglyceride turnover could readily escape from the adipocytes into the circulatory system influencing metabolic receptors associated with feeding. Both Hervey (1969) and Baile and Forbes (1974) have suggested free fatty acid and growth hormone involvement; acting on a type of dilution principle to convey messages between fat depots and the central nervous system (CNS).

It is, however, not clear from the literature if there is interaction between body condition score and milk yield potential on feed intake. Fat high yielding cows, because of their greater demand for energy,

would be expected to react differently to food compared to low yielding animals.

1.1.3.5 Disease and Stress

Infections, parasitic and metabolic diseases are consistently associated with decreased feed intakes (Baile and Forbes, 1974; Weston, 1982). Infections to the mouth and feed could also hinder feed acquisition. Psychic stress associated with strange environments results in depressed feed intake (Weston, 1982).

Why sick animals decrease their feed intake or cease to eat is not clear. One could, however, speculate that the release of chemical toxins, metabolites, hormones and increased body temperature result in a feedback to the central nervous system resulting in the cessation of feeding.

1.1.3.6 Eating Behaviour

The literature on the eating behaviour of stall-fed dairy cattle was recently reviewed (Campling and Morgan, 1981). The authors found very limited data on the eating behaviour of lactating dairy cattle. Even in the few data available, the magnitude and source of variation in eating behavioural traits were not adequately described. Diversity in objectives and experimental conditions resulting in different techniques of recording also makes it difficult to compare results from different sources (Dulphy, Remond and Theriez, 1980). In most experiments too few animals were used for any adequate measure to be made of variation between animals. Only few reports have included several cows (Burt, 1957; Dulphy et al, 1980; Tanida et al, 1984).

The study of eating behaviour requires that the approach adopted must be clearly defined. These are:

(1) number of meals/day;

(2) minimum meal duration;

(3) inter-meal interval;

(4) meal size;

(5) rate of eating (Baile, 1975).

All these parameters depend on the definition given to a meal. As feeding bouts occur sometimes very close together, it has to be decided whether consecutive bouts comprise one meal or more than one. It is, therefore, necessary to define a critical minimum meal interval in order to decide when a break in feeding can be regarded as an interruption within a meal and when it can be considered as an interval between two meals.

In the dairy cattle studied, the frequencies of interval lengths between feeding bouts have been distributed in a form of negative exponential, with short breaks of feeding occurring most often (Metz, 1975). This implies a constant probability that meals occur more or less at random. Short breaks in feeding usually occur more frequently than expected from the negative exponential, and because they are distributed differently these breaks are regarded as interruptions within meals and not as inter-meal intervals. A method of estimating this minimum inter-meal interval is the use of survivorship curves (Metz, 1975) where cumulative frequency of eating bout interruptions are plotted against eating bout interruptions. The minimum interval occurs where there is an inflexion in the straight line of the curve. This point occurs where very short intervals are no longer distributed in a negative exponential

form. Except the work of Metz (1975) who used this method and Vasilatos and Wangsness (1980) who used the value (20 minutes) derived by Metz, for dry dairy cows, most reports give no definitions of minimum inter-meal intervals or meals.

Observations on eating behaviour are either recorded continuously or at intervals (scans). These observations are either carried out by the experimenter or by the use of sophisticated machines such as time-lapse photography (Vasilatos and Wangsness, 1980) or video recording machines (Metz, 1975). Continuous observations involve fewer animals but are essential to study events on short duration behaviours. Interval observations may involve many animals and are appropriate for behaviours such as eating (Mullen et al, 1980; Smith and Hodgson, 1984). Most observations are over a 24-hour cycle (Metz, 1975; Vasilatos and Wangsness, 1980; Tanida et al, 1984). These observations indicate a diurnal pattern of eating, with peaks of eating activity occurring after fresh feed offerings and after milking (Metz, 1975; Vasilatos and Wangsness, 1980; Tanida et al, 1984). Most eating occurred between 0600 to 2100 hours of the day (Vasilatos and Wangsness, 1980; Little and Harrison, 1984; Tanida et al, 1984).

Factors identified to influence eating behaviour of dairy cattle are:

(1) physical and chemical characteristics of feed on offer;

(2) amount of food eaten;

(3) the distribution of the diet;

(4) age and size of cow;

(5) the physiological state of the cow;

(6) social behaviour (Dulphy et al, 1980; Campling and Morgan, 1981).

Fibrous and bulky feeds are eaten more slowly than less fibrous feeds and pelleted diets are eaten even more rapidly (Balch, 1971). Dairy cows eat long forage more slowly than chopped forage (Voskuil and Metz, 1973). Results summarized from the literature (Campling and Morgan, 1981) indicate that cows spent less time eating hay (215-427 min/day) than silage (242-575 min/day) when these were offered for 4 or 24 h/day. The eating rate by dry cows eating different forages was variable (range 4-58 min/kg DM). That of lactating dairy cows fed grass silage or concentrate was 29-39 and 2.4-3.9 min/kg DM respectively. The number of meals eaten per day was also variable; no doubt due to different criteria used by different experimenters for defining meals.

The type of supplemental feed added to forage does also influence eating rate (Heinrichs, Palmquist and Conrad, 1982; Harb and Campling, 1983).

The physiological state of the cow also influences eating behaviour. Lactating cows have been observed to eat more rapidly than non-lactating pregnant cows (Journet and Remond, 1976). Older, socially dominant milking cows ate forage faster than first calvers (Burt, 1957). This is not always the same in all experiments for socially dominant cows (Harb, Reynolds and Campling, 1985).

Very few experiments on eating behaviour have been observed over different stages of lactation. Recently Little and Harrison (1984) observed that the time spent eating silage and concentrate was similar at all stages of lactation (3.4-6.1 h/24 h). Linear regression of this data also showed that the amount of time spent eating silage was

inversely related to the concentrate allocated (r = -0.57). It was also noted that cows visited concentrate dispensers less frequently immediately after calving (13.9 times/day) compared with the rest of lactation (20.4 times/day).

Relationships between eating behaviour parameters and animal characteristics are variable in the literature. Dulphy et al (1980) reported, from three experiments with cows producing 12-26.5 kg/day milk, no relationship between time spent eating and milk yield, and only in one experiment was there a significant relationship between liveweight and time spent eating when maize silage or hay forages were offered ad libitum. Tanida et al (1984) could find no strong correlation between total time spent eating or the number of meals and milk yield or fat content of milk. The number of meals eaten was, however, significantly correlated (r = 0.59) with total time spent eating. Burt (1957), on the other hand, found significant correlations between liveweight and rate of eating hay but not kale or concentrate in cows. The relationship with milk yield though positive was small and not significant.

When cattle are grouped together they tend to form a social or dominance order (Coppock et al, 1981). There is discrepancy of information if social hierarchy influences the feed intake of individual cows in a group situation. Harb et al (1985) found no significant correlation between degree of dominance and variation between cows in voluntary intake of silage. Leaver and Yarrow (1980) observed that socially dominant cattle ate more than submissive cattle. There are, however, several reports indicating that socially dominant animals remained at the feed trough longer than submissive animals (Friend

et al, 1977; Harb et al, 1985), though this did not always result in higher intakes for the dominant cows due to increased rate of eating by submissive cows (Harb et al, 1985). Group feeding of dairy cows resulted in increased voluntary intake than individual feeding (Phipps et al, 1983). Whether this behaviour is due to social facilitation observed in other groups of animals such as pigs (Hsia and Wood-Gush, 1983) is not clear. Also group fed animals tend to eat together and it is clear that where there is no strong competition for feed and feed trough space this may be more advantageous than individual feeding (Coppock et al, 1981).

Strong correlations between number of meals eaten with overall meal duration ($r = -0.81$), inter-meal interval ($r = -0.61$) and meal size ($r = 0.90$) but not daily dry matter intake ($r = -0.01$) have been demonstrated (Vasilatos and Wangsness, 1980). Significant relationships between eating rate and hay intake ($r = 0.47$) when fed chopped but not when fed long ($r = 0.03$) have also been observed (Voskuil and Metz, 1973). Strong correlations between time spent eating and feed dry matter intake have not always been observed (Harb and Campling, 1985; Harb, Reynolds and Campling, 1985). This is probably due to large variation between animals in time spent eating compared to feed dry matter intake (Harb and Campling, 1985).

Factors regulating meals eaten are still unclear. Meal size seems, however, to be dependent on energy demand and on the sensory qualities of the food (Wiepkema, 1971). The factors affecting meal size in restricted and in ad libitum feeding are not, however, the same. Some factors that play a role in the control of spontaneous meals might have to be suppressed or the animal would have to develop new

thresholds of satiety in order to maintain energy balance when under conditions of sheduled feeding (Baile and Forbes, 1974).

Information on the underlying mechanisms involved in the control of meal eating can be obtained by calculating correlation coefficients between meal size and the preceding interval and between meal size and the succeeding interval (Metz, 1975; Chase et al, 1976). If meal size is positively correlated with length of the preceding interval, with large meals following long intervals and small meals following short intervals, this implies that there is a mechanism which controls the size of meals by determining the point at which feeding stops; a satiety mechanism, conversely, if meal size is positively correlated with the length of the succeeding interval, with long intervals following large meals and small intervals following small meals, this implies that there is a mechanism which controls the length of the interval by determining the point at which feeding starts; a hunger mechanism. Significant pre-prandial correlations have been found in dairy cattle (Metz, 1975) suggesting that a satiety mechanism does exist. This may indicate that satiety may play a greater part in termination of meals than hunger has in their initiation. As suggested by Metz (1975), meals tend to stop once a fixed level of repletion is reached, rather than the common belief that the next meal begins because food ingested at a previous meal was depleted.

1.1.3.7 Genetic Differences

It is not clear to what extent appetite is inherited. Reports, however, indicate differences between breeds in voluntary feed intake (Korver, 1982). Cows of low breeding index are known to eat less food during lactation than cows of high breeding index but similar amounts in the

dry period (Davey et al, 1983). Heritabilities of feed intake are estimated to be betwen 0.1-0.4 (Miller et al, 1972; Hoover et al, 1972). These estimations are greater than zero, indicating that a portion of the total variation in feed intake is controlled by additive genetic effects. The variations in estimated heritability is influenced by diet and number of animals used (Lamb et al, 1977).

1.1.4 REPEATABILITY OF VOLUNTARY FEED INTAKE

Repeatability, in animal behaviour terms, is defined as the degree to which an animal retains its position or rank in a group performing a task from time to time. This is the fraction of the variation in voluntary feed intake which is a permanent feature of an animal due to both genetic and non-genetic causes (Campling, 1980).

Observations by Ostergaard (1979) and Campling (1980) revealed a high correlation ($r = 0.7$) between the voluntary feed intake in one month with the intake in the next succeeding month, but correlations became weaker as time separated months. The accuracy of using feed intake in early lactation to predict intake in middle and late lactation is, therefore, questionable (Korver, 1982).

Coefficient of variation in total dry matter intake ranges from 5.0-14.7% (Lamb et al, 1977; Korver, 1982). This is influenced by stage of lactation, type of diet (Korver, 1982) and amount of feed on offer (Osbourn, 1980).

1.1.5 FEED INTAKE PREDICTIONS OR MODELS

Several attempts have been made to predict voluntary intake by empirical equations (Curran et al, 1970; Vadiveloo and Holmes, 1979;

Yungblut et al, 1981, see also Table 1.4) or by computer models (Monterio, 1972; Forbes, 1977, 1983).

An empirical equation, as defined by Rigg (1963) cited by Baldwin and Koong (1980), is one which has been fitted to experimental data by curve fitting so as to describe a relationship which has been observed between two or more variables. These equations imply nothing about the underlying reasons for these relationships. Factors often used in empirical equations include milk yield (MY), stage of lactation (WL), liveweight (LW), liveweight change (LWC), proportion of concentrate in the diet (C), proportion of acid detergent fibre (ADF), crude fibre (CF), digestibility of the diet (D) or other chemical components. As Broster et al (1982) pointed out there are too many factors influencing the voluntary feed intake of cows and many of these may be interdependent, therefore empirical multiple regression equations can give misleading results. Attempts at computer simulation of feed intake has so far not proved accurate (Forbes, 1977, 1983).

Recently Neal, Thomas and Cobby (1984) compared several empirical intake equations in use in the UK using data from the Grassland Research Institute. They found large errors of prediction and suggested that an insufficient number of variables were used in these equations. They also questioned the benefit of future research in the development of empirical equations. Until more is known about the interacting factors influencing intake attempts at improving various empirical equations for use at the farm level will be needed. The use of constants to adjust for environmental or other feed factors, not included in empirical equations, can improve the precision of prediction equations of feed intake (Brown et al, 1981).

The many empirical equations in use for predicting feed intake are given in Table 1.4. Even in the most successful empirical feed intake prediction equation 16% of the variation in feed intake was still left unexplained (Brown et al, 1977). A comprehensive equation based on UK conditions is that of Vadiveloo and Holmes (1979). The major factors explained 73-76% of the variation in dry matter intake.

For practical use all prediction equations should be tested against an independent source of data. Most of these empirical equations mentioned above have either not been tested in this manner or, where tested, the data have been obtained from Research Stations. Only in one case has the equation been tested on data collected from dairy farms (Yungblut et al, 1981).

Forbes (1977, 1983) has developed computer simulation models for describing the variation in feed intake and feeding behaviour of dairy cattle using metabolic, physical and endocrine factors. Monterio (1972) presented a model for predicting appetite and energy balance of cows based on physiological energy requirements. The deduced equations failed to take into account environmental or nutritional stresses on the animal's regulating system that could limit energy availability. Instead delay parameters were used to correct for perturbations in the system, such as changes in body weight and rate of milk production which change over time.

There are few mathematical models (Ostergaard, 1979) describing the curves of voluntary feed intake.

Because of the complexity in the control of feed intake and its interrelationships with energy balance regulation it is not surprising

Table 1.4 *Feed intake equations from the literature*

Equation number	Dependent variable	Prediction equation	Source
1	DMI(kg)	0.025LW + 0.1MY adjusted for early lactation by 2-3kg	MAFF (1975)
2	DMI(kg)	$0.27MY + 0.007WL + 0.135LW^{0.75}$	Greenhalgh and MacDonald (1979)
3	DMI(kg) Heifers	0.16MY + 2.45LWC + 0.0113LW + 4.25	Bines et al (1977)
4	Silage DMI(g/kg $LW^{0.75}$)	0.1027DM + 0.0516 in vitro D% + 0.05 NH_3-N + 45	Lewis (1981)
5	DMI(g/kg $LW^{0.75}$)[a]	$1.068CI + 0.000247C.SDMI - 0.00337C^2 + 0.00175MY-10-9$	Lewis (1981)
6	DMI(kg)	-5.5231 + 0.3155WL + 0.4209MY + 0.7836 Fat% + 0.3786 ADF% + 0.0096LW (R^2=78.0%)	Yungblut et al (1981)
7	DMI(kg)	3.3676 + 0.3395WL + 0.3362MY + 0.5282 Fat% - 0.1061 ADF% + 0.0096LW (R^2=78.0%)	Yungblut et al (1981)
8	DMI(kg) Early lactation	4.9 + 0.20FCM + 0.015LW (R^2=0.29%)	Bertilsson and Burstedt (1983)
9	DMI(kg) Middle lactation	-1.5 + 0.41FCM + 0.18LW (R^2=0.64%)	Bertilsson and Burstedt (1983)
10	In DMI(kg)[b]	Physiological controlled equation [0.55 - 0.46 In D + 0.51 In 2.2LW + 0.25 In 0.24PE]/0.45 (R^2=81.0%)	Conrad et al (1964)
11	In DMI(kg)	Physical controlled equation [1.53 In D + 1.01 In 2.2F + 0.99 In 2.2LW - 5.3]/0.45 (R^2=82.0%)	Conrad et al (1964)
12	In DMI(kg)[c]	0.519776 (± seasonal factor) - 0.000827DL + In 0.148073DL + 0.33922MY + 0.000675LW + 0.018001CF% - $0.000557CF^2$(%) (R^2=74.1%)	Brown et al (1977)
13	DMI(kg)	0.430C + 0.015LW - 0.095WL + 4.0401LogWL + 0.208MY (R^2=71.9%)	Vadiveloo and Holmes (1979)

FCM = Fat corrected milk; [b]F = Faecal output; PE = Physiological energy; D = Digestibility coefficient (%); [a]SDMI = Silage dry matter intake; [c]DL = Days in lactation.

that predictions are only poor guides when applied to specific situations (Curran et al, 1970; Baile and Della-Fera, 1981; McCullough, 1983). Accuracy is only possible on farms providing conditions similar to those in which predictive equations were developed (Campling, 1980).

1.1.6 CONCLUSION

Short-term regulation of feed intake has been attributed to chemostatic regulation whereas long-term regulation is attributed to lipostatic theory. Blood and rumen volatile fatty acids, in ruminants, are acknowledged to be involved in chemostatic control of feed intake instead of glucose. Hormones and free fatty acids are probably involved in long-term regulation of feed intake.

The potential voluntary feed intake of the dairy cow can be modulated by several animal factors such as the physiological state of the animal (lactating, pregnant or growing), body size and body condition. In addition, intake is influenced by feed, environment and management factors. The digestibility, cell wall contents and protein content of the diet, the type of conservation or treatment of the forage are all part of feed factors influencing feed intake (Figure 1.2).

Due to the complexity of factors influencing potential feed intake, attempts at voluntary feed intake predictions are only approximations. Computer simulations of voluntary intake are also not precise at the moment.

1.2 Factors Affecting Energy Utilization

1.2.1 INTRODUCTION

The conversion of dietary energy to product depends on the following

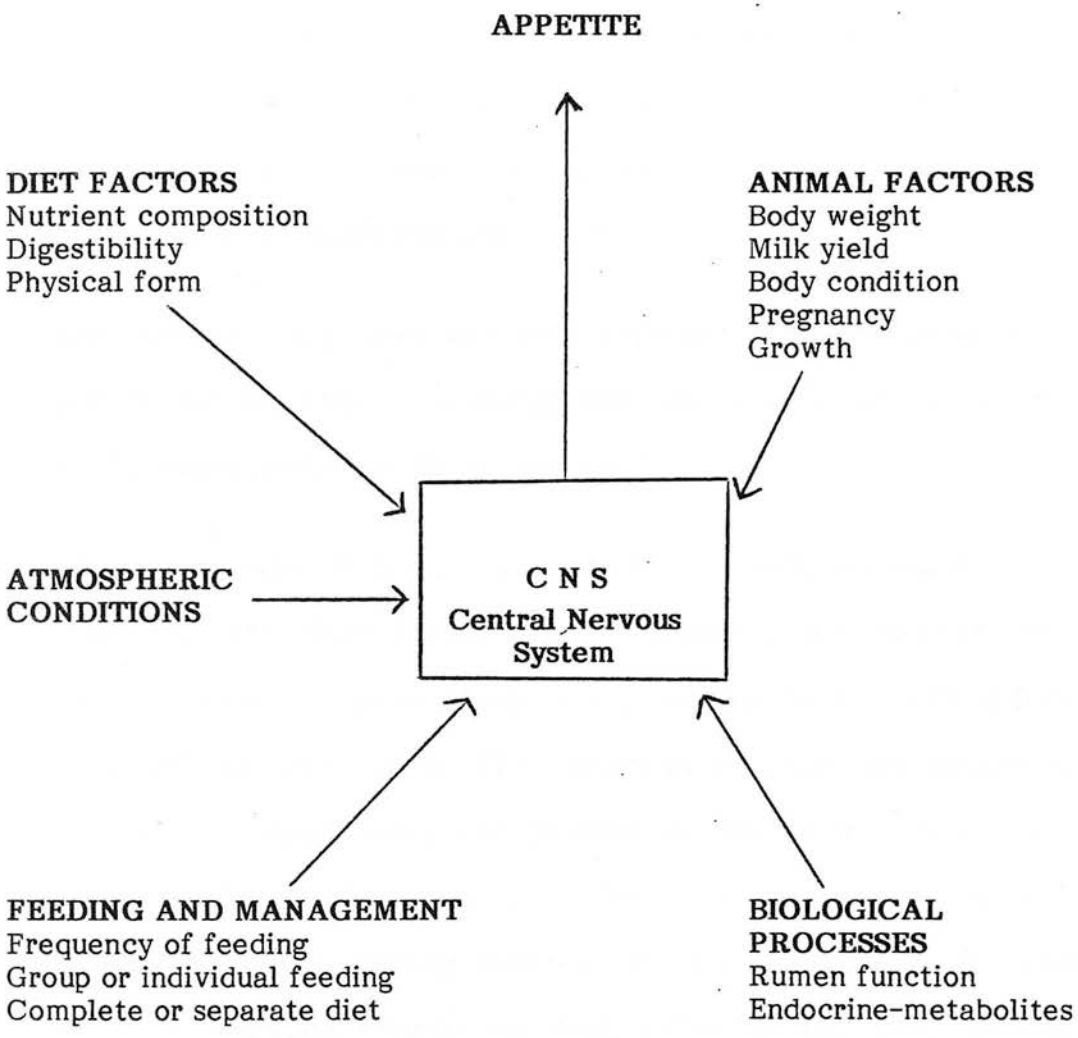


Figure 1.2 Schematic representation of factors influencing voluntary feed intake

metabolic sequences within the animal's body:

(1) fermentation and digestion of food;

(2) absorption of nutrients;

(3) metabolism of the absorbed nutrients for maintenance of body structure and synthesis of products;

(4) relationship between output products as milk and materials stored in tissues (Webster, 1979).

The feed of dairy cows contains, chemically, mostly carbohydrates, protein and fat with gross energy (GE) values of about 17, 24 and 40 MJ/kg respectively (Van Es and Van Der Honig, 1979).

Energy, however, is not a nutrient but a property possessed by these nutrients. The chief mechanisms for energy in the body is through the high energy bonds of adenosine triphosphate (ATP). ATP is formed from volatile fatty acids (VFA) which result from the fermentation of dietary carbohydrates and proteins in the rumen. Metabolizable energy (ME) is stored in ATP for maintenance and production (Armstrong, 1969). During fermentation of food 5-12% of the energy is lost as methane (Tyrrel and Moe, 1975; Van Es, 1976), 10-70% in the faeces and 2-8% in urine (Van Es, 1976). Heat of fermentation which represents 5-10% of energy intake is considered as part of ME (ARC, 1980). Available ME is partitioned between maintenance and production. Only lactation requirements will be reviewed in this thesis. Maintenance requirements were provided by Van Es (1972).

1.2.2 LACTATION REQUIREMENTS

The relationship between milk energy (LE, KJ/day) and ME intake supplied above maintenance requirements is confounded with tissue

energy deposition (positive RE, KJ/day) or mobilization (negative RE, KJ/day) (Van Es and Vander Honig, 1979).

The efficiency of utilization of ME for milk production (K_l) range from 54-68% (Van Es, 1976; Van Es and Vander Honig, 1979; Moe, 1981). This variability is attributed to the variable maintenance requirements used by different workers for calculating k_l (Van Es, 1972; Moe and Tyrrel, 1974, 1975). This is also due to different diets utilized by different experiments (Van Es and Vander Honig, 1979). For traditional dairy cattle diets containing 10-12 MJ ME/kg DM K_l is betweeen 61 and 66% (ARC, 1980).

Because of the inherent problem of separating the confounding effects of tissue energy from milk energy, multiple regression equations of the type:

$$[LE + a \text{ (positive RE)} + b \text{ (negative RE)}]/W^{.75} = K_l \text{ ME intake}/W^{.75} + C$$

have been used to estimate maintenance and K_l values. Values of a and b were estimated as 1.0 and 0.80-0.84 respectively and K_l was 60-64% (Moe et al, 1971; Van Es and Vander Honig, 1979). Indicating that during lactation tissue energy can be used with an efficiency of 80-84% for milk synthesis. Partial efficiency of ME for body gain during lactation and dry period was 75 and 60% respectively by regression techniques (Moe et al, 1970, 1971). The temporary storage of energy as fat in late lactation and its mobilization in the next lactation for milk production is less efficient than the direct use of dietary ME for milk production (48 vs 60%) (Van Es and Vander Honig, 1979). This is even less efficient if the fat is deposited during the dry period (40%).

Estimates of efficiency of utilization of energy intake for milk production from non-calorimetric data range from 40.6-56% due to the different energy systems used (Jumah et al, 1965; Johnson, 1983; Phipps et al, 1984b). The ME required for synthesis of 1 kg FCM range between 4.85-5.48 MJ and is dependent on the K_l values used, the calorific value of weight change used, and the metabolizability of the diet (Alderman et al, 1974; Moe and Tyrrel, 1974; MAFF, 1975; Van Es and Vander Honig, 1979).

1.2.3 FACTORS OF ANIMAL ORIGIN

Both dietary and animal characteristics influence the utilization of energy for maintenance and lactation. Dietary factors are:

(1) metabolizability (q) or energy concentration (M/D) of the diet;

(2) fat content;

(3) processing or type of diet;

(4) protein content;

(5) plane of nutrition.

Animal characteristics are:

(1) parity;

(2) body condition;

(3) stage of lactaton;

(4) pregnancy;

(5) genetic potential;

(6) hormones;

(7) milk composition.

Only the influence of animal characteristics on energy utilization are reviewed here. Readers are referred to Moe (1981) and Garret and Johnson (1983) for a review on the influence of diet characteristics

on energy utilization.

1.2.3.1 Parity

There is a paucity of information on the effect of parity on the efficiency of ME utilization for milk production. Several reports, however, do show that heifers produce less milk than higher parity cows even when this is expressed on a metabolic body size basis (Cowan et al, 1981; Strickland and Broster, 1981). They also respond less in milk yield to incremental additions made to diets than cows (Strickland and Broster, 1981).

In an experiment to compare the energy partition at two stages of lactation (approximately 72 and 130 days) between heifers and cows, Brown, Tyrrel and Williams (1983) observed no significant differences in ME intake and milk energy production when this was expressed per unit metabolic size. They concluded that heifers were able to partition energy to milk similar to cows. The results also showed that heifers have the ability, in early lactation, to mobilize body tissue towards milk production; with very little growth in the first 210 days of lactation. Oldenbroek (1984a,b) observed that heifers of different breeds partitioned 48-51% of their energy intake into milk in their first lactation and 44-55% in their second lactation; this was breed dependent.

1.2.3.2 Body Condition

The influence of body condition or fatness on ME requirements is unclear. Body fatness does not seem to influence digestibility (Reid and Robb, 1971; McNiven, 1984). Maintenance requirements tend to be greater following a high plane of nutrition than a low plane of nutrition (Reid and Robb, 1971). Experiments with sheep indicate

lack of effect of body fatness on maintenance and lactation energy requirements (McNiven, 1984). With cattle, however, there are discrepancies in the literature on the influence of body fatness on maintenance requirements. Wright (1982) observed lower maintenance requirements for fat beef cows than thin cows whereas Thomson et al (1983) showed the opposite.

Body nutrient stores play an important role in the lactation cycle especially in early lactation when energy intake lags behind requirements (Broster and Alderman, 1977). There is speculation that mobilised tissue fat may be critical to the realisation of a cow's milk production potential (Hemken, 1971; Bines and Hart, 1982). Some reports demonstrated increased milk yields with good conditioned cows at calving (Davenport and Rakes, 1969; Yadava et al, 1970; Broster, 1971; Frood and Croxton, 1978; Land and Leaver, 1981; Wildman et al, 1982; Grainger et al, 1982). Other reports failed to show any advantage of good body condition at calving on milk yield (Land and Leaver, 1980; Garnsworthy and Topps, 1982b; Boisclair et al, 1984). There seems to be an advantage though on milk fat yield (Grainger et al, 1982; Boisclair et al, 1984). Body tissue energy is, however, efficiently utilized when its influence on health and feed intake is not detrimental (Moe et al, 1971).

The amount of energy mobilized from body tissues to milk depends on the quantity of body fat and energy intake (Moe et al, 1971; Cowan et al, 1981; Garnsworthy and Topps, 1982b; Grainger et al, 1983; Kuntz et al, 1985). There, however, appears to be a limit to body tissue loss and once this is reached then milk production decreases to a level which is supported by dietary intakes (Botts et al, 1979; Wildman et al,

1982).

Liveweight change has traditionally been used as an estimate of body fat mobilization, though a few reports using body condition score are available in the literature (Steen and Gordon, 1980a,b; Garnsworthy and Topps, 1982b). Queries on its use have been raised especially in early lactation (Moe et al, 1971). Gut fill, hydration and dehydration have been implicated as causing variation in liveweight change (Moe et al, 1971; Trigg and Topps, 1981; Alderman et al, 1982). Analysis of cull cow data has failed to support the hydration or dehydration theory of fat mobilization (ESCA Annual Report, 1983).

Liveweight change is greater in:

(1) heifers than cows (Miller et al, 1969; Smith et al, 1978);

(2) animals on high planes of nutrition pre-calving (Davenport and Rakes, 1969; Lodge et al, 1975);

(3) fat animals at calving (Garnsworthy and Topps, 1982b).

Attempts to avoid body weight loss in early lactation have not been successful; this can, however, be minimized by high level of nutrition in early lactation (Johnson, 1979, 1983; Broster and Broster, 1984).

There are conflicting reports on the contents of body tissue mobilized. Cowan et al (1981); Bines and Hart (1982); Butler Hogg et al (1983) contend that only fat is mobilized whereas others argue that both fat and protein are mobilized (Bath et al, 1966; Belyea et al, 1979; Botts et al, 1979; Trigg et al, 1980; Chilliard et al, 1983). Differences between experiments seem to be due to differences in level of nutrition and the genetic potential of animals used in the various experiments (Chilliard et al, 1983).

Calorific value of liveweight change ranged from 10-39.5 MJ/kg (Bath et al, 1965; Reid and Robb, 1971; Moe et al, 1971) or 20-66 MJ/kg (MAFF, 1975; ARC, 1980; Alderman et al, 1982). This is not surprising since this value will depend on the varying fat, water and protein content of weight change. Calorific value of liveweight change in early lactation is therefore meaningless because of the difficulty of measuring true weight change (Moe et al, 1971).

The mechanisms involved in body tissue mobilization are unclear though they are part of the homeostasis and homeorhesis mechanisms of the animal (see Bauman and Currie, 1980). Increased fat mobilization in early lactation is by increased lipolysis. Diminished activity in adipose tissue is then brought about by either endocrinological changes or due to negative energy balance (Metz and Vanden Bergh, 1977).

1.2.3.3 Stage of Lactation

The efficiency of utilization of energy for milk production defined as milk energy divided by ME intake is higher in early lactation compared to late lactation (Korver, 1982; Custodio et al, 1983; Johnson, 1983; Oldenbroek, 1984a,b etc). This is because in early lactation milk yield is high and tissue gain is low, that is partition favours milk yield rather than body gain (Flatt et al, 1969; Orskov et al, 1977). Bauman and Currie (1980) calculated that cows with a peak yield above 35 kg 4% FCM mobilized energy equivalent to 50 kg pure lipid or 9 kg milk per day during the first 10 weeks of lactation.

1.2.3.4 Milk Production Potential

There is no clear indication from metabolic studies of differences in maintenance metabolism at different production levels (Van Es,

1972). Energy requirements are probably not influenced by the potential of the cow for milk production (Tyrrel and Moe, 1975). Total feed efficiency must increase with the potential of the cow because the constant factor of maintenance makes a smaller proportion of the total energy requirements at higher production (Van Es and Vander Honig, 1979; Wiktorsson, 1980).

Tyrrel (1980), reviewing the limits to milk production, concluded that the partial efficiency of metabolic functions (milk synthesis, body tissue synthesis and body tissue transfer to milk) in the lactating cow is not subject to large variation. In contrast, individual cows differ substantially in the manner in which they partition absorbed nutrients (Bauman et al, 1985). Animals of high genetic merit have greater appetites and the ability to mobilize body reserves early in lactation for higher milk production than those of low merit (Bryant and Trigg, 1981; Davey et al, 1983; Bauman et al, 1985).

1.2.3.5 Pregnancy

Pregnancy imposes a substantial additional cost to the animal in nutrient demand resulting in decreased availability of nutrients for milk synthesis (Bauman and Currie, 1980). Efficiency of utilization of ME for pregnancy is also very low (10-25%) (Moe et al, 1970; ARC, 1980). The part which mammary development plays in the pregnancy burden is not well documented (Bauman and Currie, 1980). Nutrients are probably diverted away from lactation to body tissues (Swan, 1976).

1.2.3.6 Hormones

Variation in the partition of energy between milk and body tissues within breed and between breeds is largely of genetic origin and probably

mediated via differences in endocrine balance (Bines and Hart, 1982; Bauman et al, 1985). Growth hormone, insulin, prolactin, glucagon and thyroid hormones are probably all involved in energy partition with insulin and growth hormone being of real importance (Trenkle, 1978; Bines and Hart, 1982). Administration of exogenous growth hormone resulted in increased milk yield, milk protein and fat yields without increase in feed intake (Bines et al, 1980). Growth hormone levels are also naturally high in early lactation but low in late lactation (Swan, 1976). The influence of growth hormone on energy partition has been attributed to its lipolytic activity and its ability to antagonise the effect of insulin and partition nutrients away from tissues to milk (Bines et al, 1980). This hypothesis is supported by higher levels of growth hormone recorded in underfed cows than liberally fed dry cows (Hart and Simmonds, 1981) and also when lactating (Hove and Blom, 1973). Growth hormone tends to promote tissue growth when nutrient supply is adequate and promotes energy mobilization when nutrient supply is limited (Trenkle, 1978). Kronfeld (1982) is of the opinion that growth hormone and insulin act synergestically rather than antagonistically to increase lipogenesis in adipose tissue through the utilization of acetate and lipolysis through the release of long chain fatty acids for milk fat synthesis.

The role of insulin in the control of metabolism is essentially anabolic (Basset, 1980). It tends to divert energy away from milk into body tissues (Weekes and Grodden, 1980; Bines and Hart, 1982).

1.2.3.7 Milk Composition

The effect of dietary energy supply on milk composition is complex (Sutton, 1984; Thomas, 1984). Milk fat content is influenced by the

type of energy intake and rumen fermentation (Rook, 1976; Oldham and Sutton, 1979; Thomas and Rook, 1982; Sutton, 1984). Fermentations that favour increased acetic and butyric acids to propionic acid (expressed as lipogenic to glucogenic ratio) favour high fat content. Non-glucogenic ratios (NRG) below 3.5 lead to milk fat depression (Armstrong and Prescott, 1971). Diets, therefore, high in concentrates depress milk fat content (Sutton, 1984).

The influence of energy intake on protein content are difficult to elucidate. A low plane of nutrition, however, depresses milk protein content (Oldham and Sutton, 1979). Milk protein content is increased by 0.0036 units per MJ increase in dietary net energy intake (Emery, 1978). The end products of digestion rather than energy per se seem to influence milk protein content (Thomas, 1984). Low acetic to propionic ratios, for example, result in increased milk protein content (Rook, 1976).

Energy intake does not seem to have an important effect on lactose content of milk, though underfeeding can cause slight depression; this is, however, marked during starvation. This effect is due to a decrease in the relative contribution of lactose to the osmotic pressure of milk as the volume of milk secretion is depressed (Kronfeld, 1982).

1.2.4 CONCLUSION

Due to different assumptions concerning maintenance requirements, different k_l values have appeared in the literature. For dairy type diets ($q = 0.55-0.70$) k_l is approximately 62%.

Body reserves (energy) are used with an efficiency of 84% to produce

milk. The efficiency of deposition of body reserves during lactation is 75% but 60% in the dry period. It is therefore more efficient to produce milk directly from dietary energy than body reserve energy.

Animals of high genetic merit produce more milk, have greater voluntary intakes and can use more of their body reserves early in lactation than those of lower merit. Body fatness per se probably influences maintenance requirements and milk fat yield.

Exogenous hormones can also influence the partition of energy toward either milk or tissue deposition.

1.3 Factors Affecting Protein Utilization

1.3.1 INTRODUCTION

Three major compartmental areas of the ruminant digestive tract are involved in the utilization of protein:

(1) the rumen;

(2) abomasum;

(3) small intestines, caecum and colon (Thomas and Chamberlain, 1981).

A major part of product synthesis is, however, carried out in the body proper.

Protein ingested in the feed by the dairy cow is made up of true protein and non-protein nitrogen (NPN), with true protein forming 80% of immature forage (Hogan, 1982). The ingested protein is degraded extensively in the rumen, depending on pre-treatment and degradability, to amino acids, peptides and ammonia, and the NPN to ammonia. There

is also endogenous recycling of urea and other endogenous protein into the rumen. Amino acids, peptides and ammonia in conjunction with energy (ATP), from the fermentation of organic matter, are used to synthesis microbial protein (Tammiga, 1978). Synthesised microbial protein, undegraded dietary protein and endogenous body protein pass to the intestines where they are digested and absorbed. Absorbed protein is metabolised and used for maintenance of body tissues and for production of milk (Thomas and Chamberlain, 1981).

The use, therefore, of digestible crude protein or per cent crude protein per kg dry matter of feed to describe protein requirements of lactating dairy cattle fails to consider the protein supplied by rumen microbes (Satter and Roffler, 1975; Roy et al, 1977; ARC, 1980). Recent proposals for calculating protein requirement of dairy cattle, therefore, require that the degradability of each feed protein within the rumen be known for the estimation of both microbial and undegraded protein (Roy et al, 1977; ARC, 1980). It is, however, not the aim in this thesis to provide a comprehensive review of the literature on the new system of protein requirements. Comprehensive reviews on this topic are provided in the literature (Tammiga, 1979; ARC, 1980, 1984; Thomas and Chamberlain, 1981; Broster and Oldham 1982; Orskov, 1982; Oldham, 1984).

The objective in this thesis is to provide a review of the literature on the influence of animal characteristics on protein utilization of dairy cows.

1.3.2 LACTATION REQUIREMENTS

Traditionally, digestible crude protein and per cent crude protein in

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the dry matter of the diet were used to describe the lactation protein requirements of the dairy cow. As already mentioned, these measures of protein requirements can be criticized. Where ME and dry matter intake are defined, protein requirements can be expressed as per cent crude protein per kg dry matter (Broster and Oldham, 1982) especially in early lactation (Krohn and Andersen, 1980).

The literature on the protein requirements for lactation is extensive and was recently reviewed (Broster and Oldham, 1982). Genetic potential for milk production, protein source, length of experimental period or stage (part) of the lactation used for experiments were interacting factors identified as influencing protein requirements.

Protein requirements for milk range from 13% (Swan, 1982) to 16% (Oldham, Fulford and Happer, 1981) and 17-20% crude protein in the diet (Cressman et al, 1980; Barney et al, 1981; Phipps et al, 1981). Reports with grass silage diets indicate a milk production response to increasing crude protein up to 22% (Gordon et al, 1982).

Using the new system of definition of protein requirements (ARC, 1980), Wilson and Wood (1983) calculated that for animals producing 34-50 kg milk per day the rumen degradable protein (RDP) and undegradable protein (UDP) requirements were 1816-3296 and 789-1278 grams respectively at an ME intake of 232-335 MJ/day. Hogan (1975) estimated the essential amino acid requirements for a cow weighing 640 kg at week 4 of lactation and producing 44, 30 and 14 kg of 30 g protein per kg milk at week 4, 22 and 44 as 832, 582 and 327 g per day respectively. For practical diet formulation ARC (1984) has recommended the use of total essential amino acids (TEAA). This

is assumed to make up 53% milk protein and 48% of duodenal digesta. For 1 kg milk containing 4.8 gN the protein requirement is:

TEAA (g/day) = 4.8 x 6.25 x 0.53 = 15.9

EAA required at the duodenum (g) = 15.9/0.80 x 0.85 = 23.4

where the efficiency of utilization of amino acid = 0.85 and the absorption coefficient = 0.80.

Microbial EAA supplied at the duodenum (g)

= 7.8 ME intake x 0.48

= 3.7 ME intake

EAA from undegraded protein required

= (23.4 - 3.7 ME intake)/0.48

= 52 - 8.2 ME intake

If it is assumed that the degradability of protein is 0.60 for mixed rations (Broster and Oldham 1982), then:

Dietary protein required (g/day)

= 52 - 8.2 ME intake/0.40

1.3.3 FACTORS OF ANIMAL ORIGIN

Both the characteristics of the animal and those of the feed influence the utilization of protein by dairy cows. The feed characteristics are natural protein or NPN, degradability of protein, energy-protein ratio, particle size, retention time in the rumen, sufficiency of the diet for microbial protein synthesis and chemical or physical attention of the protein source (Huber and Kung, 1981); this is, however, not reviewed in the thesis. The animal characteristics reviewed include genetic potential, stage of lactation, body fatness or condition and parity (Oldham, 1984).

1.3.3.1 Genetic Potential of Animals

Animals of higher genetic milk production potential have higher protein requirements especially in early lactation when voluntary intake is low (Journet and Remond, 1976; Wilson and Wood, 1983). Due to their higher production level, gross efficiency of protein use for milk production is also higher than average (Jumah et al, 1965; Broster and Oldham, 1982). This seems not to be the case in all instances (Foldager and Huber, 1979; Custodio et al, 1983). All available evidence suggests that animals of higher genetic potential are more efficient in protein use for milk production than low genetic potential animals. This is principally due to the maintenance being a smaller proportion of total production plus maintenance requirements.

1.3.3.2 Stage of Lactation

Protein requirements and gross efficiency of protein utilization are higher in early lactation (Edward et al, 1980; Grieve et al, 1980; Lindell, 1982; Custodio et al, 1983) no matter which units are used. Satter and Roffler (1975) have drawn attention to a need for increased undegraded protein in early lactation. This is due to low voluntary feed intake and the disproportionate use of energy and protein from mobilized tissues in early lactation. Physiological conditions of the cow, in early lactation, result in a higher metabolic efficiency and a more efficient utilization of dietary protein for milk production (Oldham, 1984).

1.3.3.3 Parity

Cows in first lactation do not respond to different protein concentrations in the diet in the same way as mature cows. In experiments in which mature cows were compared with first calvers, higher protein diets

resulted in higher dry matter intakes and a concomitant increase in milk yield in cows but not in heifers (Roffler et al, 1978; Poos et al, 1979; Cressman et al, 1980). Other reports found no differences between heifers and cows (Cowan et al, 1981; Roffler and Thacker, 1983). Added protein in early lactation, however, improved milk yields in all parity groups in 9 out of 10 cases when these experiments were examined (Roffler and Thacker, 1983). Milk yield responses were, however, greater for cows than heifers in 8 out of 10 comparisons. These differences in responses between cows and heifers reflect differences in secretory capacity and the metabolic drive of heifers to achieve mature size (Oldham, 1984).

1.3.3.4 Body Condition

Reports on the influence of body condition on protein utilization are limited. Animals in negative energy balance can be forced to increase this negative energy balance by infusing, post-ruminally, casein. The rationale is that cows in negative energy balance require extra amino acids from the intestines to match available mobilized tissue which has low protein content. Amino acid supply then stimulates tissue mobilization (Orskov et al, 1977). A summary of published trials shows that liveweight loss decreases with increasing protein input (Oldham and Smith, 1981). This is thought to be due more to energy intake rather than protein intake (Krohn and Andersen, 1980). Increasing protein input, however, increases ration digestibility and/or food intake. The increased energy intake spares energy released from tissues, reducing liveweight loss.

In early lactation, because of dietary protein shortage, protein is mobilized from tissues to contribute to an amino acid pool. Estimates

of protein content of liveweight change vary from 190 (Bath et al, 1965) to 150 g/kg (ARC, 1980). Labile protein reserves, on the other hand, have been estimated as 7 (Satter and Roffler, 1975); 21-24 (Botts et al, 1979); 25 (Parquah et al, 1972) and 15 kg (Chilliard and Roberlin, 1983). This represents 5-25% of total body protein.

1.3.4 CONCLUSION

Requirements of the dairy cow for amino acids are met from two sources:

(1) microbial proteins synthesised in the rumen and later digested and absorbed in the small intestines;

(2) undegraded dietary protein digested and absorbed directly in the intestines.

High milk production potential cows are more efficient in protein utilization for milk production than low potential ones. They also require more protein in early lactation.

Cows convert dietary protein to milk production more efficiently in early than later in lactation.

Cows on average convert dietary protein to milk production more efficiently than heifers.

1.4 Methods For Assessing Body Composition of Live Animals

There are several methods in use for assessing the body composition of live dairy cattle, only methods used in the present thesis (liveweight, weight change, condition score and ultrasonic measurements) will be briefly described.

1.4.1 LIVEWEIGHT AND LIVEWEIGHT CHANGE

Liveweight is the most common objective measurement made on live animals. Most predictive equations or indexes of body composition are traditionally judged against liveweight alone or other additional information supplied in combination with liveweight.

Liveweight tends to be a less useful index of ruminant body composition because of large variations in gut fill which can range between 5-30% of weight (Reid and Robb, 1971; Rohr and Daenicke, 1984). There is at present no practical means of estimating weight of gastrointestinal contents.

Liveweight change is another indispensable measure of estimating animal performance in feeding trials and production systems. With balanced diets liveweight change at a given body weight essentially depends on energy intake. On forage based diets, however, variations in gut fill may be so large as to render liveweight change meaningless (Rohr and Daenicke, 1984). Liveweight change as a measure of body tissue change can be improved if average dry matter intakes are taken into account (Rohr and Daenicke, 1984).

Changes of feed, management and environment can all contribute to measured liveweight (Broster et al, 1980). Repeated weighings on successive days is reported to improve the accuracy of estimated weight change but not completely remove the bias (Broster et al, 1980). Serial weighings at two week intervals plus standardisation of weighing time, in particular relative to feeding and milking, has proved beneficial in measuring weight changes and revealing bias due to gut fill.

1.4.2 BODY CONDITION SCORING OF CATTLE

There has been interest in finding ways of estimating, by visual appraisal, the amount of body fat in dairy cattle. Previously, terms such as fat, lean and medium were used in experiments. These qualitative terms made it difficult to compare results between experiments. Recently body condition scoring in suckler cows (Lowman, Scott and Sommerville, 1976) and dairy cattle (Mulvaney, 1977) was developed. In this scoring system two areas of a cow's body are assessed for fat cover:

(1) spinous processes of the lumbar vertebra;

(2) around the tail head.

The system defines a 5-grade scale from 1-5 and is scored to the nearest quarter. Body condition score avoids the problems of gut fill but may be relatively slow to indicate the need to change a diet (Broster et al, 1980).

Studies on the reproducibility of condition score has been made (Evans, 1978; Nichols, 1981). The correlation coefficients of repeat scores on the same animal by the same operator were high ($r = 0.80$ for an experienced operator). Reproducibility between operators is not so high (Evans, 1978; Nichols, 1980); though Evans obtained 0.70 in some instances. Differences between operators trained together tend to be negligible (Broster et al, 1980).

There is paucity of information on the relationships between body condition, liveweight and body composition. Due to the discrete nature of condition scoring its relationship with continuous variables such as liveweight or body composition measures (energy, protein and fat) can never be perfect. One unit change in condition score was equivalent

to 49-110 kg liveweight change for beef cattle (Kilkenny, 1979; Wright, 1982) and 17-75 kg in dairy cattle (Frood and Croxton, 1978; Gordon, 1984; Moisey and Leaver, 1984). Differences exist between cows and heifers in these relationships (Frood and Croxton, 1978; Moisey and Leaver, 1984). The wide ranges of liveweight change per unit condition score change reported are probably due to variations between operators in condition scoring and to effects of gut fill due to different diets used in these experiments.

Only in one report has condition score been related to body energy, protein and fat (Wright, 1982). He observed that one unit change in condition score of the empty body was equivalent to 52.6-84.1 kg fat, 1.18 kg ash, 7.35 kg protein, 2242-3478 MJ energy and 22.2 kg water across different breeds of beef cattle.

1.4.3 ULTRASONIC MEASUREMENTS

Earlier work using ultrasonic measurements was aimed at predicting commercial characteristics of animal carcass (Simm, 1983a). Attempts at using ultrasonic measurements to predict body composition seem almost non-existent in the literature. Only in one experiment (Wright, 1982) known to the author was there an attempt to predict body composition from ultrasonic fat depth measurement.

The ultrasonic technique is based on the principle that high frequency soundwaves are transmitted through animal tissues and when these reach an interface between two tissues of differing densities some of the sound is reflected back. There are 4 basic parts to ultrasonic equipment:

(1) pulse generation which transmits electrical pulse;

(2) a transducer which converts electrical pulse to ultrasonic pulse;

(3) an amplifier which amplifies electrical current;

(4) an oscilloscope which displays a current on a screen or film.

The transducer is normally placed on the skin of the animal and the ultrasound is transmitted to the tissues (Andersen, 1975; Simm, 1983a).

Two types of ultrasonic machines are commonly used in the UK. The "Danscanner" which provides a permanent record of the ultrasound by photographing the image on an oscilloscope screen and the "Scanogram" which uses photographic film as the screen itself.

Ultrasonic measurements of live animals are carried out on subcutaneous fat area of the loin and back. In this region the musculature consists mainly of the M longissimi thorácis et lumborum (eye muscle) which is easy to measure. Scannings are done at the 3rd lumbar and 13th and 10th ribs. Various correlations between ultrasonic fat depth or area measurements and carcass traits have been reported (Wright, 1982; Simm, 1983b). Several authors have expressed doubts about the reliability of this technique. Gibson and Alliston (1983) and Simm (1983b) argued that the objectivity of ultrasound measure was reduced by operator interpretation of anatomical boundaries in the scanning picture.

Ultrasonic measurements of body fat may therefore suffer from similar errors and subjectivity difficulties as condition scoring. The use of one operator may reduce this bias, although not necessarily make results from different experiments and operators easy to compare.

2 GENERAL MATERIALS AND METHODS

2.1 ORIGINAL DATABASE

The experiment was conducted during 6 winter feeding periods from September 1979 to December 1984 using first and subsequent parity British Friesian/Holstein dairy cows from the Edinburgh School of Agriculture's Langhill herd. Each year, during the first 5 years, 40 animals were used in the experiment (Table 2.1) and were recorded over 24 weeks of lactation. In year 6, 33 animals were used for feeding behaviour studies (see Chapter 7).

Since 1973 the Langhill herd of 200 pedigree British Friesians has been involved in a long-term breeding project operated by the Edinburgh School of Agriculture and by the Agricultural and Food Research Council Animal Breeding Research Organisation supported by the Milk Marketing Boards of England and Wales and the Scottish Milk Marketing Board. The objective of the project is to investigate the scope for genetic improvement in yield and milk components through the use of artificial insemination and national breeding services, and to evaluate management practices that will allow improved genetic potential to be expressed. To facilitate the genetic project common management and nutrition are applied to the whole herd.

The management and feeding has 4 main objectives:

(1) Provide each animal with the same opportunity to express genetic potential to enable comparisons between the selected and control herds.

(2) Encourage high dry matter intake (DMI) during lactation to exploit cow potential.

(3) Gradually introduce any changes in diet to minimise any upsets

Table 2.1 Lactation number of cows in the experiment

	LACTATION NUMBER					
YEAR	**1**	**2**	**3**	**4**	**>4**	**TOTAL**
1		12	6	9	12	39*
2		7	14	4	14	40
3		10	11	9	9	39*
4	25	-	6	5	4	40
5	26	14				40
Total	51	43	36	27	39	198

* Cow culled from experiment due to disease

associated with sudden change in diet.

(4) Maximise the use of high quality silage in the diet.

The milking herd is fed complete diets during the winter housing period. This started in the winter of 1978/79 when the herd was housed in new cubicle accommodation. A small quantity, 0.8 kg per milking, of concentrate was fed in the parlour in order to encourage the animals to enter the parlour and settle down during milking.

2.2 General Management of the Experimental Cows

Cows for use in the experiment were trained to use Calan-Broadbent electronic gates (Broadbent, McIntosh and Spence, 1970) 6-8 weeks pre-calving, when dried off. First calvers were also trained 6-8 weeks pre-calving. About 7-10 days before expected day of calving cows were taken off grass and housed in straw-bedded courts.

Animals were introduced to individual feeding gates within 7 days of calving. All animals were housed in cubicles bedded with sawdust in a loose house. Manure was removed at 6-hour intervals by an automatic scraper.

The complete diets fed to the animals were mixed daily in a Farmhand horizontal mixer wagon. Individual allowances were weighed out in bins each day in quantities sufficient to provide ad libitum intake (this was based on 5-10% feed refusals). Diets were made up from grass silage, brewers' grains and concentrate balancer meal (Appendix Table A.67). The concentrate was formulated to contain 13 MJ metabolizable energy (ME) per kg dry matter (DM) and 200 g crude protein and also to meet recommended mineral and vitamin requirements (ARC, 1965, 1980). The mean composition of the concentrate mix (kg per tonne) was:

500	barley
230	wheat
137	soya bean meal
40	bone and meat meal
30	white fish meal
33	fat premix
15	wheating
15	minerals and vitamins

The complete diets were formulated depending on stage of lactation. Animals were fed diets containing 11.8 MJ ME per kg DM (M/D) and 160 g crude protein per kg DM. About 100 days post-calving the energy content of the diet was gradually reduced to about 11.5 MJ/kg DM until week 24 of lactation by adjusting the forage:concentrate ratio (Appendix Tables A.68-A.70). Drinking water was offered ad libitum from self-filling water troughs.

The animals were milked twice daily, through a 16:16 herringbone parlour at 05.00 and 15.00 h. All disease incidences when diagnosed by the veterinarian were recorded. Reproductive status of the animals was also checked. Reproductive targets were first oestrus by 46 days post-calving, first service by 77 days post-calving or within 3 weeks of the start of the service period starting in December and pregnancy by 99 days after calving.

2.3 Animal Recordings

2.3.1 LIVEWEIGHT (LW), CONDITION SCORE (BS) AND BACKFAT AREA (BFA)

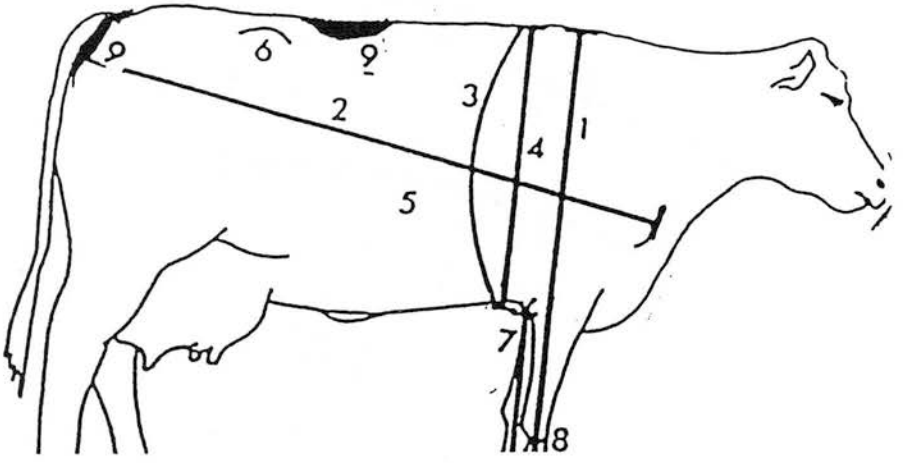
The LW of all experimental animals was recorded within 48 h after

calving and then weekly, at approximately the same time of the day each occasion. To reduce problems of gut fill, the liveweight for a particular week was taken as the mean of 3 consecutive weeks; that is the LW in the current week and those of the preceding and succeeding weeks. The rationale behind this method of LW recording is given in Appendix Chapter 1. Liveweight change was calculated as current LW minus preceding LW.

The animals were condition scored (Lowman, Scott and Somerville, 1976, Figure 2.1) immediately after calving and then every 4 weeks during the first year and every week in succeeding years. Each cow, in the first 4 years of the experiment, was ultrasonically scanned using a 'Danscanner' (Medico Technical Institute, Copenhagen) within 7 days of calving and then at weeks 6, 12 and 18 of lactation. In the first 3 years of the experiment cows were scanned at 3 sites on each occasion (over the 10th and 13th ribs and 3rd lumbar vertebra) at right angles to the spine. In the 4th year scanning was at only 2 sites (13th rib and 3rd lumbar vertebra). There was no scanning in the 5th year. Photographs were recorded for each position and these were traced using a Summa graphic digitizer (Summa Graphics Ltd) (Figure 2.2). From each photograph a fat area was taken at 16 cm in length over the Longissimus dorsi muscle centred at a point where a line drawn from the deepest position in the Longissimus dorsi muscle at right angles to the hide crossed the subcutaneous fat layer (Figure 2.2a). Recordings from the 3 or 2 areas were averaged giving a single fat area designated as backfat area for each cow at each scan time. BS change or BFA change was calculated as BS or BFA measured in weeks 6, 12 and 18 of lactation minus calving BS or BFA measures.

Figure 2.1 Live body measurements

1 HEIGHT AT WITHERS
2 LENGTH SHOULDER POINT TO PIN BONE
3 HEART GIRTH
4 DEPTH OF CHEST
5 WIDTH OF CHEST (AT WIDEST POINT)
6 HOOK BONE WIDTH
7 LENGTH OF LEG (LEFT FORELEG — FROM POINT OF ELBOW)
8 CANNON BONE CIRCUMFERENCE (LEFT FORELEG — IMMEDIATELY BELOW KNEE)
9 CONDITION SCORE



How to Condition Score:

The condition scoring system is based on handling two areas of the cow to assess the level of fat cover or body tissue reserves. These are the loin area (i.e. between the hip bone and last rib) and around the tail head. The loin area is the main area for condition scoring. However, above a condition score of three, the bones around the loin can no longer be felt and the amount of fat cover around the tail head is also used to assess the condition score of the cow.

Condition Score 1

The individual spinous processes are sharp to the touch and easily distinguished.

Condition Score 2

The spinous processes can be identified individually when touched, but feel rounded rather than sharp.

Condition Score 3

The spinous processes can only be felt with very firm pressure and areas on either side of the tail head have some fat cover.

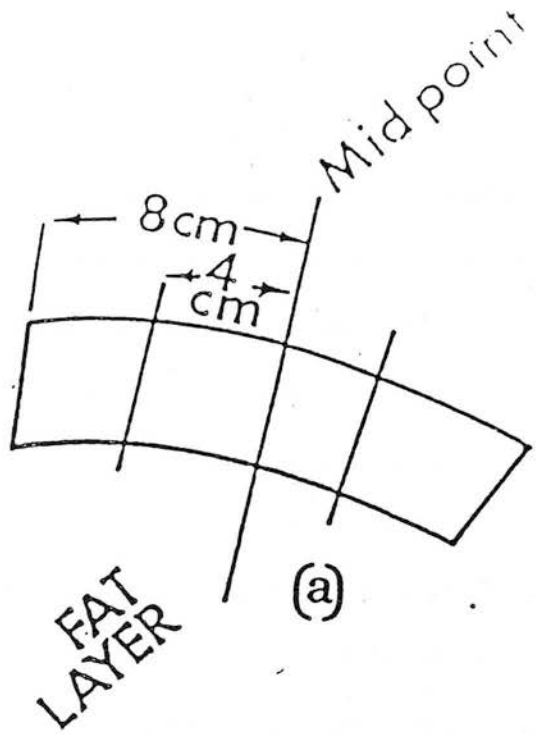
Condition Score 4

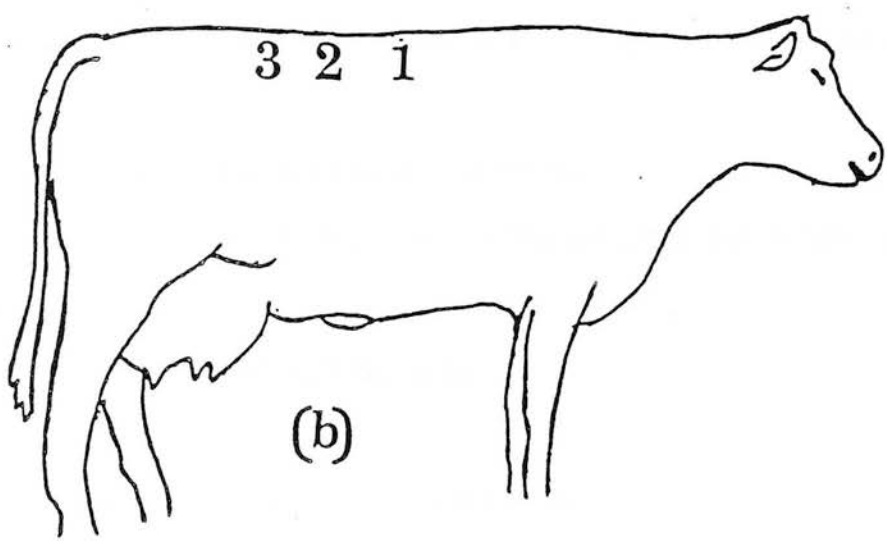
The spinous processes cannot be felt, fat cover around the tail head is easily seen as slight mounds, soft to the touch.

Condition Score 5

Fat cover around the tail head is extensive and rolling. Dairy cows very seldom reach this condition score.

Figure 2.2 Backfat area measurement: (a) fat area traced by summa graphic digitizer and (b) ultrasonic scanning sites





1- 10th Rib
2- 13th Rib
3- 3rd Lumbar Vertebra

2.3.2 MILK YIELD AND MILK COMPONENTS RECORDING AND ANALYSIS

Milk yields were recorded weekly as the sum of Tuesday afternoon and Wednesday morning milkings. Milk composition was analysed, monthly in the first year and fortnightly in succeeding years. Samples of milk (250 ml) were taken from the Tuesday afternoon and Wednesday morning yield to give a representative sample of the yield at each milking, and forwarded to the Central Testing Laboratory, Scottish Milk Marketing Board for analysis. Butterfat and protein were determined with a milkosan 300 infra red analyser (Foss Electric UK Ltd). These analyses were standardised by the Gerber method for butterfat and the Kjeldahl method for protein determinations. Milk composition in the week where analysis did not take place was estimated as the mean of the fat and protein composition of the preceding and succeeding test.

Fat corrected milk (FCM) kg per cow per day was calculated as (Gaines, 1928):

FCM = milk yield x (0.4 + 0.15 milk fat %)

Energy value (EV) of milk was calculated from the following equation (ARC, 1980)

EV (MJ/kg) = 0.0406 milk fat (g/kg) + 1.509

2.4 Feed Intake Recording and Feed Analysis

2.4.1 CHEMICAL ANALYSIS

The weight of fresh complete diet offered and refused was recorded on 4 consecutive days (Monday through Thursday) to the nearest 0.1 kg,

weekly. The 4 days recording was found to be representative enough for individual weeks (see Appendix Chapter 1). Daily composite samples of the complete diet and individual feed refusals were taken and dried in a forced draught oven at 60°C for 72 h to give oven dry matter (ODM). In 1983/84, fortnightly, toluene dry matter (TDM) was determined on the silage in the complete diet and on the complete diet to establish a relationship between ODM and TDM (see Appendix Chapter 1 for details).

Each week a sample of silage and complete diet were bulked and analysed for DM, at 60% for 72 h in a ventilated oven, for crude protein (N x 6.25) by a micro Kjeldahl digestion technique modified for use with an auto-analyser, modified acid detergent fibre (MADF) as described by Clancy and Wilson (1962), and in vitro organic matter digestibility (Alexander and McGowan, 1969). In addition, the ammonia nitrogen (NH_3-N) of the silage was determined using an ion selective electrode with a concentrate meter and the pH using a Beckman digital pH meter. Ash was determined in a muffler furnace at 500°C for 24 h. Yearly DM of the feed offered over the experimental period is provided in Appendix Figure A.4

2.4.2 CALCULATED DRY MATTER INTAKE (DMI), METABOLIZABLE ENERGY (ME) INTAKE AND NITROGEN INTAKE

The DMI of the feed was calculated as:

DMI (kg/cow/day) = fresh food offered x DM of fresh food - feed refulsals x DM of feed refusals

This was then converted to toluene DMI by multiplying by a factor of 0.967, developed from the relationship of ODM and toluene DM (see Appendix Chapter 1).

Concentrate DMI was also calculated as:

Concentrate DMI (kg) = concentrate (kg/kg DMI) x DMI (kg)

The ME intake was expressed in megajoules (MJ) per cow per day and was estimated as the total supply from the complete diet and the parlour nuts (concentrate). The ME values were estimated from in vitro digestibility of the organic matter in the dry matter (DOMD) as:

ME (MJ/kg DM) = (DOMD x 19.8) x 0.81 (Blaxter, 1982)

Where 19.8 is the gross energy per kg DM and 0.81 is a correction factor for energy losses in methane and urine. The ME of the parlour nuts was estimated from tabular values of the constituents (ARC, 1965, 1980).

During the 3rd (1981/82) and 5th year (1983/84) of the experiment samples of the complete diet were collected during the winter feeding period, deep frozen and energy balance trials were carried out using wether lambs (see Appendix Chapter 1 for details). ME estimated from in vitro OMD over-estimated ME determined with sheep by 0.4-1.8 MJ/kg DM.

Nitrogen (N) intake was expressed in g/cow/day. Nitrogen intake was calculated from the complete diet and parlour nuts as:

DM intake x % nitrogen in DM + parlour nuts DMI x % of N in the parlour nuts

Degradability of the main ingredients of the complete diet (silage, brewers' grains and concentrate) was determined with 3 fistulated sheep by the method described by Mehrez and Orskov (1977) (see Appendix Chapter 1 for details).

The calculations of the supply of microbial nitrogen, rumen degradable

protein nitrogen (RDN), undegradable protein nitrogen (UDN) and essential amino acid N supply (EAAS) to tissues were based on computational methods described in ARC (1980 and 1984) using values of degradabilities determined for silage, concentrate and brewers' grains.

2.5 Calculations of Requirements for Maintenance and Milk Production

The ME and essential amino acid (EAA) requirements for maintenance and milk production were expressed as MJ and g/day respectively (ARC, 1980, 1984) (See Table 2.2 for calculations).

2.6 Feed Selection

To be sure the cows were not selecting the complete diet mixture, resulting in underestimation of ME intake, samples of fresh feed supplied and individual feed refusals were collected and analysed for MADF, N and ash and then compared. There were no differences in composition between feed fed and feed refusals coming from the same feedbin indicating no significant selection of the diet. (Details are provided in Appendix Chapter 1).

2.7 Prediction of Body Composition from Live Animal Measurements

Nineteen cows were culled during a period of 3 years and slaughtered to provide both live measurements and body compositional data. Prediction equations derived from this data was used to estimate efficiency of ME utilization for milk yield in Appendix Chapter 4. Details can be found in Appendix Chapter 3.

Table 2.2 Calculations of maintenance and milk production metabolizable energy and nitrogen requirements, and energy and nitrogen efficiency

	REQUIREMENT	ESTIMATION EQUATION[a]
1	Maintenance energy (Z, MJ ME/cow/day)	$(0.53\ (LW/1.08)^{0.67} + 0.0043LW)/k_m$
2	Lactation energy (R, MJ ME/cow/day)	$(1 + 0.018\ (L-1)\ (EV/k_l))$
3	Maintenance total amino acid N (TN_m, g/day)	$0.35\ LW^{0.75} + 0.018\ LW^{0.75}$
4	Lactation essential amino acid N (EAA_L, g/day)	[MY x protein concentration in milk (g/kg)]/6.38x0.53
	EFFICIENCY	
5	Energy balance (MJ ME/day)	ME intake - Z - R
6	Gross efficiency	EV/ME intake
7	Net efficiency	EV/(ME intake - Z)
8	Productive ME intake/FCM (MJ/kg)	(ME intake - Z)/FCM yield
9	Nitrogen efficiency	Milk nitrogen yield/nitrogen intake
10	EAA retained (g/day)	(Total TAA - TN_m) x 0.53 - EAA_L

[a] LW = liveweight
K_m (efficiency of utilization of ME for maintenance) = 0.019M/D + 0.503
K_l (efficiency of utilization of ME for lactation) = 0.019 M/D + 0.42
L = level of feeding above maintenance
M/D = metabolizable energy in the diet
EV = daily milk energy yield
MY = daily milk yield
TAA = tissue amino acid N supply
0.53 = factor for converting milk total nitrogen to essential amino acid N

2.8 Organisation of Data for Statistical Analysis

The data of the 5 years were partitioned into 2 trials. Trial 1 covered years 1-4 of the experiment and provided information on differences between cows (parities 2-10). Trial 2 covered years 4 and 5 and provided information on differences between heifers, second parity and older cows (parities 3-7).

Since the main objective of the experiment was to study the trend and influence of various environmental and animal characteristics over different stages of the lactation period, the 24 week experimental period was divided into stages (periods of lactation). Stage 1 was weeks 2-6 (period of peak milk yield), Stage 2 weeks 7-12, Stage 3 weeks 13-18 (period of peak DMI), Stage 4 weeks 19-24 and Stage 1-4 weeks 2-24 (Broster et al, 1982). The first week of the experiment was dropped for lack of records on most animals. The data were further edited and animals with less than 24 weeks of lactation or more than one week of records missing from any period were dropped from the analysis. The number of observations used in the analysis for various factors are indicated in Table 2.3.

The factors were:

Year of calving, divided into year classes 1, 2, 3 and 4.

Month of calving, divided into 3 classes, class 1 (September), class 2 (October) and class 3 (November and December).

Parity classes for Trial 1 were 2, 3 4 and 5 where 5 includes all parities subsequent to 4.

Parity classes for Trial 2 were 1a, 1b, 2 and 3 where 1a was heifers in year 4, 1b heifers in year 5, 2 parity 2 animals and 3 includes all parities subsequent to 2. Heifers were separated into years due to

Table 2.3 Data organization per different factors

TRIAL 1

FACTOR	NUMBER OF OBSERVATIONS
YEAR OF CALVING	
1	33
2	35
3	35
4	12
MONTH OF CALVING	
1	47
2	56
3	12
PARITY	
2	26
3	34
4	25
5	30
MILK YIELD GROUP	
1	16
2	45
3	54
CONDITION SCORE GROUP	
1	65
2	26
3	24

TRIAL 2

PARITY GROUPS	
1a	24
1b	26
2	14
3	12
MONTH OF CALVING	
1	27
2	24
3	24

significant differences between the 2 groups in production traits (Table 2.4).

Calving condition score groups were 1 (less than 3.00 condition score units, BSU), 2 (3.00-3.50 BSU) and 3 (more than 3.50 BSU) (Frood and Croxton, 1978).

Milk yield in week 2 was classified into 3 classes. Class 1 was for animals producing less than 25 kg milk/day, class 2 25-30 kg milk yield/day and class 3 more than 30 kg milk yield/day (Johnson, 1977).

The traits per stage of lactation were based on the average of the measuring points within the stage.

In Table 2.4 are provided the unadjusted means of liveweight, condition score and backfat area at calving and the milk yield in week 2 of lactation for the different factor classes for Trials 1 and 2. There were significant ($P < 0.5$) differences between years, parities and calving condition score groups in liveweight, condition score and backfat area at calving.

2.9 Statistical Analysis

2.9.1 INTRODUCTION

The analysis of survey or observational data requires special attention due to the impossibility of experimental control and the resulting lack of structure of the data. Some of the factors affecting the results will be inherent in the system being observed and not imposed by the experimenter. Some factors will have well-defined distinct levels whereas others will be represented throughout a range of values. When all factors have distinct levels an observed data value - the dependent variate - can be estimated from the levels of each factor relevant

Table 2.4 Means, standard errors (se) of liveweight at calving (kg), calving backfat area (cm^2) and condition score (1-5 units) and daily milk yield in lactation week 2 (kg) per different factors - Trials 1 and 2

Trait		Calving Liveweight		Backfat area		Calving Condition Score		Milk Yield	
Factor	Number of records	Mean	Se	Mean	Se	Mean	Se	Mean	Se
All	115	636	7.8	6.41	0.213	3.07	0.065	30.6	0.65
Year of Calving									
1	33	632[a]	12.5	7.29[a]	0.339	2.65[a]	0.103	28.5	1.10
2	35	667[b]	12.5	7.17[a]	0.337	3.61[b]	0.103	31.8	1.14
3	35	638[a]	11.2	6.89[a]	0.303	3.17[c]	0.092	30.2	0.93
4	12	607[c]	19.6	4.30[b]	0.530	2.87[d]	0.162	32.0	1.64
Month of Calving									
1	47	620	9.9	6.25	0.268	2.88	0.082	29.9	0.84
2	56	638	9.6	6.47	0.261	3.00	0.079	29.1	0.80
3	12	651	18.6	6.52	0.503	3.34	0.153	32.9	1.55
Parity									
2	26	553[a]	14.9	5.25[a]	0.404	2.73[a]	0.123	28.6	1.40
3	34	641[b]	12.3	6.89[b]	0.332	3.09[b]	0.101	31.0	1.01
4	25	667[c]	13.1	6.67[b]	0.354	3.09[b]	0.108	31.1	1.10
5	30	683[d]	12.7	6.83[b]	0.344	3.39[c]	0.105	31.8	1.11
Milk Yield Groups									
1	16	621	17.8	6.79	0.438	2.74	0.155	21.3[a]	0.76
2	45	630	12.2	6.98	0.300	3.08	0.106	28.2[b]	0.52
3	54	658	10.7	6.82	0.630	3.16	0.093	34.0[c]	0.46

Continued/...

Table 2.4 continued

Trait / Factor	Number of records	Calving Liveweight Mean	Calving Liveweight Se	Backfat area Mean	Backfat area Se	Calving Condition Score Mean	Calving Condition Score Se	Milk Yield Mean	Milk Yield Se
Calving Condition Score Group									
1	65	607[a]	8.5	6.29[a]	0.230	2.55[a]	0.035	29.3	0.68
2	26	655[b]	12.9	7.18[b]	0.345	3.18[b]	0.054	28.8	1.04
3	24	719[c]	13.9	8.08[c]	0.376	4.27[c]	0.057	31.8	1.11
				TRIAL 2					
All	75	556	5.2			2.77	0.033	24.8	0.92
Month of Calving									
1	27	564	7.4			2.69	0.039	26.0	0.86
2	24	560	8.1			2.76	0.044	26.1	0.86
3	24	578	8.3			2.74	0.046	27.8	0.91
Parity Groups									
1a	24	524[a]	10.5	4.44	0.165	2.81	0.060	19.2[a]	0.49
1b	25	538[b]	10.3	-	-	2.64	0.059	21.9[b]	0.81
2	14	579[c]	14.1			2.74	0.080	33.6[c]	1.11
3	12	607[d]	19.6	4.30	0.536	2.87	0.162	32.0[d]	1.64

abcd Different superscripts in column indicate significant difference $P < 0.05$

to that unit, eg

$$y_{ijk} = M + A_i + B_j + e_{ijk}$$

Where y_{ijk} is the observation on the kth unit of the ith level of factor A and the jth level of factor B.

A_i is the response over all units receiving level i of factor A

B_j is the response over all units receiving level j of factor B

and e_{ijk} is the deviation of the observation on this unit from that expected

Analysis of variance estimates the parameters M, A_i and B_j so that

$S_{ijk} (y_{ijk} - M - A_i - B_j)^2$ is a minimum

i.e. the sum of squared deviations

$S_{ijk} e_{ijk}^2$ is a minimum

The fitting of this model to the data assumes that the effects of factors A and B are independent, i.e. the response to level i of factor A is not affected by the level (the same for all levels) of factor B and v.v. and that deviations e_{ijk} are $N(0, \sigma^2)$.

If the effects of factors A and B are not independent, i.e. the level of one affects the response at a particular level of the other, the model has to be modified to include this 'interaction', i.e.

$$y_{ijk} = M + A_i + B_j + A_iB_j + e_{ijk}$$

The parameters are now estimated by minimising

$$S_{ijk} (y_{ijk} - M - A_i - B_j - A_iB_j)^2$$

When values of some factors affecting the dependent variate cannot be expressed as distinct levels, they have to be included in the model

in a different way, eg

$$y_{ijk} = M + A_i + B_j + cC + e_{ijk}$$

Here the values of factor C are distinct for each unit and the model assumes that the effect of C on the dependent variate is proportional to its size; c is called the regression coefficient of y on C. Factor C is co-variate, i.e. a variate which changes along with the dependent variate and which cannot be controlled within the terms of the investigation.

When the number of units in different levels of factors A and B vary, a regression analysis is to be preferred to normal analysis of variance because of lack of orthogonality or balance between factors whether co-variates are included in the model or not. Again, the total of squared deviations is minimised.

The present data were therefore analysed with a least squares statistical computer program written to handle non-orthogonal data (Harvey, 1977).

2.9.2 ANALYSIS

Trial 1

The model to be fitted is (Model 1)

$$y_{ijklmn} = M + A_i + U_j + L_k + P_l + C_M + P_lC_m + b_1R + b_2W + e_{ijklmn}$$

Where y_{ijklmn} is the observation of the nth cow in the i, j, k, l, m level of calving year, month, parity, milk yield in lactation week 2, condition score respectively.

M is the general response over all levels of the factors

A_i is the effect of year of calving

U_j is the effect of month of calving

L_k is the effect of parity of cow

P_l is the effect of milk yield in lactation week 2

C_m is the effect of calving condition score

R is the effect of average weekly body weight change during the stage of lactation

W is the effect of liveweight at calving

P_lC_m is the effect of interaction between the lth milk yield in lactation week 2 and mth calving condition score

b_1, b_2 are regression coefficients describing the relations of body weight change and liveweight to the dependent variate

and e_{ijklmn} is the residual deviation of unit n from the value fitted by the model

In the first analysis the effects of days open, interaction between year of calving and milk yield, parity and milk yield, parity and condition score at calving were small and not significant ($P < 0.05$). For these reasons these factors were dropped from the model. Other two-way interactions could not be fitted due to empty cells in some of the factor classes.

In the second analysis individual linear and quadratic regressions of calving condition score, weight change and calving weight on the dependent variables were fitted for each year, parity and milk yield class. Only significant ($P < 0.05$) class regressions are presented.

The independence of the residuals was investigated, that is correlations between subsequent lactations from the same cow. The difference of between cow and within cow variation was small and the correlation

coefficients between the average milk yield of one period or stage of lactation and a similar period in the next year were small. The correlation coefficients between the average dry matter intake in similar periods of 2 succeeding lactations by the same cow were also low to moderate in size (Table 3.4). For these reasons, dependence of the residuals from one lactation with another was not considered to influence the validity of the analysis.

The null hypothesis of no effects of factors under study, in the model, on the dependent variable was tested with the F-test; where F is mean square divided by error mean square.

Differences between levels of treatment effect were tested with the 95% least significant difference (LSD)

where LSD = t x SEM

where t = 97.5% point of the student t distribution with degrees of freedom (df) equal to error df of the analysis of variance

SEM = standard error of the overall least squares mean of the dependent variable

Similarly Trial 2 data were analysed by the following model (Model 2)

$y_{ijk} = M + U_i + L_j + b_1R + b_2W + b_3P + b_4C + e_{ijk}$

where

y_{ijk} is the observation of the kth cow in the mth month of calving and jth parity

M is the general response over all levels of the factors

R is the effect of weekly body weight change during the stage of lactation

W is the effect of liveweight at calving

P is the effect of milk yield in lactation week 2

C is the effect of condition score at calving

b_1, b_2, b_3, b_4 = regression coefficients

e_{ijk} = residual term

All other analyses are as described for Model 1. Also individual parity class linear or quadratic regressions were fitted for weight at calving, calving condition score, milk yield in lactation week 2 and weekly liveweight change on the dependent variables. Only significant ($P < 0.05$) class regressions are reported.

To obtain the variance (R^2) explained by each factor on certain dependent variables, they were dropped from the full models (Model 1 and Model 2). Difference between the R^2 explained by the full model and R^2 accounted for by the shortened model equals the variance explained by the factor dropped from the model.

2.10 Analysis of Models of Curves of DMI, Milk Yield, Liveweight and Condition Score

Dry matter intake, milk yield, liveweight and condition score were recorded weekly. These variables tend to change over time so a hypothetical underlying mathematical model could be fitted to within cow data. The parameters of the model could then be analysed with Models 1 and 2.

The model $y_t = at^be^{-ct}$ (Wood, 1967) was fitted to dry matter intake and milk yield curves from week 2 through to week 24 of lactation. In the model y_t = is the average daily dry matter intake and milk yield of a cow in week t and a, b and c are parameters:

a is related to initial feed intake or milk yield

b is the rate of increase to peak intake or milk yield

c represents the rate of decline from peak

b/c is time to peak intake or yield

c^{-b-1} is persistency of milk yield

e is exponential

A quadratic function was fitted to liveweight and condition score patterns over the experimental period. The model was $Y_t = a + bt + ct^2$ where y_t = liveweight (kg) or condition score at time t and a, b and c are coefficients to be estimated.

The parameters and components of the various curves were compared between different factor levels using Models 1 and 2.

The hypothetical models of these curves explained in milk yield 58.2, 72.6, 68.8, 65.2 and 75.0%; in dry matter intake 49.6, 50.5, 54.1, 59.5, 60.5%; in liveweight 65.6, 72.0, 71.2, 83.7 and 80.6%, and in condition score 68.4, 62.0, 60.8, 46.2 and 48.9% of the variation for years 1-5. Due to high week to week variation in these traits the models could not fit these curves perfectly.

II INTRODUCTION

The most important animal factors influencing voluntary intake (VFI), as described in Chapter 1, were: milk yield, pregnancy, liveweight, parity or age, body condition (fatness) and eating behaviour. These then interact with feed quality, management practices and environmental factors to influence potential VFI.

To study the influence of animal characteristics on VFI of dairy cows requires that feed quality, management practices and environmental factors be controlled. In long-term experiments, however, due to changing rainfall patterns and weather conditions grass quality changes causing differences in feed quality between months and years of calving. The design of the present experiment therefore requires that the influence of environmental factors be accounted for in the estimation of the effects of animal characteristics on VFI.

The few experiments which investigated long-term feed intake, utilized average values of animal characteristics in different stages of lactation (eg Curran et al, 1970; Vadiveloo and Holmes, 1979). Furthermore, these researchers were concerned mostly with predicting VFI for practical farm use rather than studying the biological reasons behind the estimated significant regression coefficients.

To the author's knowledge there is no report in the literature where attempts have been made to study the effects of animal characteristics, immediately post-partum, on VFI and the possibility of predicting VFI from these characteristics. Yet the influence of animal characteristics on VFI in early lactation, when animals are not able to consume enough feed to meet

requirements, probably has an important effect on milk production over the whole lactation period (Broster, 1974).

In the Chapters (3 to 6) following, the influence of animal characteristics (calving liveweight and condition score and daily milk yield in lactation week 2) on VFI, milk production, nutrient utilization and liveweight and condition score changes respectively are studied. In addition, the effects of weekly liveweight change within the stage of lactation, parity and environmental factors (years and months of calving) on these same traits are also studied.

Chapter 7 provides information on eating behaviour patterns and the relationship between eating behaviour and VFI of dairy cattle in early, middle and late lactation.

In Appendix Chapter 4 the effect of animal characteristics within the stage of lactation on VFI and nutrient utilization is reported.

Chapter 8 provides a general discussion of all results and provides suggestions for future research.

3 VOLUNTARY DRY MATTER INTAKE

3.1 Results

3.1.1 GENERAL

Dry matter intake (DMI, kg/day), daily dry matter per 100 kg liveweight (DMI%) and dry matter intake per metabolic body size ($DMI/W^{0.75}$, g/day) are given in Tables 3.1 and 3.2 for Trials 1 and 2 respectively. DMI showed the typical increase with time following the onset of lactation. In Trials 1 and 2 DMI increased steadily reaching maximum intakes (measured as mean daily dry matter intake during the week in which the highest total weekly feed intake was attained) of 22.6 kg (3.51% of liveweight or 178 $g/W^{0.75}$) and 20.6 kg (3.63% of liveweight or 177 $g/W^{0.75}$) in lactation weeks 15 and 16 respectively. Thus the highest DMI occurred in lactation stage 3 (weeks 13-18) for both trials. However, when intakes of dry matter were expressed as DMI% or $DMI/W^{0.75}$ the highest intakes occurred in lactation stage 2 (weeks 7-12) probably because the minimum lactation liveweights occurred about this time. Over 2-24 weeks of lactation intakes of dry matter averaged daily 19.4 kg (2.96% of liveweight or 149 $g/W^{0.75}$) and 18.0 kg (3.15% of liveweight or 154 $g/W^{0.75}$) for Trials 1 and 2 respectively.

Variations in DMI between animals was greater in lactation stage 1 (weeks 2-6) when coefficient of variation (CV%) was 13.4 and 13.8 respectively for Trials 1 and 2. However, between animal DMI variation tended to decline with increasing time from calving, as intake of dry matter increased, until lactation stage 3 when CV was 12.2 and 11.0% for Trials 1 and 2 respectively. About 4.1 (Trial 1) to 6.5 (Trial 2) and

2.1-3.3% units of the between animal DMI variation (CV) in lactation stages 1 and 3 respectively was due to a combination of environmental and animal factors.

In Trial 1, expressing DMI as DMI% failed to reduce the between animal DMI variation, whereas expressing DMI as DMI/$W^{0.75}$ reduced this variation (CV) by 0.3-0.7% units. However, in Trial 2 expressing DMI as DMI% and DMI/$W^{0.75}$ reduced CV by 1.5 and 2.0% units respectively in lactation stage 1 and by only 0.3 and 0.8% in lactation stage 3. Due, perhaps, to the inconsistent between animal DMI variation during different lactation stages, correlations between DMI in one stage of lactation and the next stage of lactation declined as the time between the stages increased (Table 3.3). Within cow correlations between DMI in the same stage of lactation in consecutive lactations were small and ranged from 0.18 (lactation stage 1) to 0.60 (lactation stage 4 (weeks 19-24) - Table 3.4.

3.1.2 EFFECTS OF DIFFERENT FACTORS ON VOLUNTARY DRY MATTER INTAKE

The different definitions of daily dry matter intake (DMI, DMI% and DMI/$W^{0.75}$) were analysed by Model 1 (see Chapter 2), Trial 1, which included the factors years and months of calving, parity, daily milk yield in lactation week 2 (MY), calving condition score (CS), MY x CS, calving liveweight, weekly weight change in the stage of lactation and by Model 2 (Trial 2) which included the above factors except years of calving and MY x CS. Model 1 explained 41.3-60.1, 38.2-65.0 and 36.0-60.4% of the total variation, in various stages of lactation, in DMI, DMI% and DMI/$W^{0.75}$ respectively for Trial 1 (Table 3.1). Similarly, Model 2

Table 3.1 Means, standard deviations (SD), residual standard deviations (RSD) and variance accounted (R^2) by Model 1 for dry matter intake (DMI) traits per stage of lactation - TRIAL 1

TRAIT	MEAN	SD	RSD	R^2(%)
DAILY DRY MATTER INTAKE (kg):				
STAGE 1	17.5	2.35	1.60	60.1
2	19.8	2.44	1.96	44.7
3	20.0	2.45	2.03	41.3
4	18.4	2.31	1.82	46.3
1-4	19.4	2.03	1.54	50.4
MAXIMUM DMI (kg)	22.6	2.52	1.99	46.2
WEEK FROM CALVING TO MAXIMUM INTAKE	15.4	8.0	7.0	19.6
DAILY DRY MATTER INTAKE/ LW(%):				
STAGE 1	2.78	0.372	0.238	65.0
2	3.14	0.387	0.293	50.7
3	3.10	0.381	0.320	39.3
4	2.82	0.354	0.300	38.2
1-4	2.96	0.320	0.236	53.0
MAXIMUM INTAKE	3.51	0.434	0.345	45.6
DAILY DRY MATTER INTAKE/ $W^{0.75}$ (g):**				
STAGE 1	139	17.7	11.9	60.4
2	157	18.4	14.6	46.0
3	156	18.2	15.7	36.0
4	142	17.1	14.6	37.1
1-4	149	15.1	11.1	46.5
MAXIMUM INTAKE	178	19.8	16.2	42.2
DRY MATTER INTAKE CURVE PARAMETERS*:				
a	13.9	3.17	2.72	36.0
b	0.276	0.235	0.163	30.6
c	-0.0251	0.0177	0.0111	28.8

* a = scaler

b = rate of increase (kg/day) in DMI from lactation week 2 to lactation week of maximum intake

c = rate of decline (kg/day) in DMI from week of maximum intake to lactation week 24

** = liveweight$^{0.75}$

Table 3.2 Means, standard deviations (SD), residual standard deviations (RSD) and variance accounted for (R^2) by Model 2 for dry matter intake (DMI) traits per stage of lactation - TRIAL 2

TRAIT	MEAN	SD	RSD	R^2(%)
DAILY DRY MATTER INTAKE (kg):				
STAGE 1	16.7	2.30	1.23	74.9
2	18.6	2.37	1.44	67.3
3	18.6	2.05	1.43	57.4
4	17.7	1.95	1.49	48.0
1-4	18.0	1.96	1.21	66.0
MAXIMUM DMI (kg)	20.6	2.38	1.76	51.4
WEEK FROM CALVING TO MAXIMUM INTAKE	16.0	12.9	9.3	27.1
DAILY DRY MATTER INTAKE/ LW(%):				
STAGE 1	3.04	0.374	0.231	66.4
2	3.33	0.372	0.276	51.5
3	3.23	0.365	0.281	47.6
4	2.98	0.357	0.289	42.4
1-4	3.15	0.327	0.223	58.8
MAXIMUM INTAKE	3.62	0.425	0.300	56.0
DAILY DRY MATTER INTAKE/ $W^{0.75}$ (g):**				
STAGE 1	147.4	17.4	11.1	64.3
2	161.8	17.2	12.9	50.3
3	158.1	16.2	13.0	43.9
4	147.0	16.0	13.4	37.6
MAXIMUM INTAKE	177.0	18.6	13.7	52.4
DRY MATTER INTAKE CURVE PARAMETERS*:				
a	13.7	2.81	2.02	53.9
b	0.2331	0.1305	0.1304	11.7
c	-0.0205	0.0136	0.0128	21.3

* a = scaler

b = rate of increase (kg/day) in DMI from lactation week 2 to lactation week of maximum intake

c = rate of decline (kg/day) from week of maximum intake to lactation week 24

** = liveweight$^{0.75}$

Table 3.3 Correlation coefficients between the same daily dry matter intake variables in different periods of lactation for both Trials 1 and 2

PERIODS OF LACTATION (Wk)	2-6 x 7-12	2-6 x 13-18	2-6 x 19-24	2-6 x 2-24	7-12 x 13-18	7-12 x 19-24	7-12 x 2-24	13-18 x 19-24	13-18 x 2-24	19-24 x 2-24
TRAIT										
TRIAL 1										
Daily dry matter intake	0.764	0.476	0.407	0.753	0.724	0.583	0.908	0.810	0.893	0.827
Daily dry matter intake/ LW(%)	0.763	0.478	0.404	0.756	0.750	0.637	0.924	0.837	0.901	0.841
Daily dry matter intake/ $W^{0.75}$	0.747	0.433	0.364	0.730	0.726	0.594	0.913	0.816	0.889	0.825
TRIAL 2										
Daily dry matter intake	0.856	0.716	0.537	0.869	0.845	0.698	0.949	0.863	0.946	0.844
Daily dry matter intake/ LW(%)	0.818	0.642	0.495	0.820	0.843	0.719	0.946	0.883	0.943	0.865
Daily dry matter intake/ $W^{0.75}$*	0.809	0.614	0.438	0.810	0.817	0.669	0.939	0.860	0.934	0.837

Trial 1 = Correlation coefficients > 0.254 $P < 0.01$

Trial 2 = Correlation coefficients > 0.302 $P < 0.01$

* = metabolic body size

Table 3.4 Correlation coefficients between dry matter intake in consecutive lactations of the same cow and regression coefficients (b) of 2nd parity cows on 1st parity cows of the same cow

WEEKS OF LACTATION	2-6	7-12	13-18	19-24	2-24
Second parity and older cows[a] (n = 30)	0.253	0.547	0.543	0.564	0.604
First parity cows vs second* parity cows (n = 14)	0.139	0.434	0.741	0.656	0.741
b ± SE	1.279±0.0364	1.189±0.0249	1.127±0.0188	1.025±0.0227	1.151±0.0144
All parities (n = 44)[c]	0.178	0.455	0.507	0.602	0.571

[a] = Correlation coefficients > 0.355 P < 0.05

* = Correlation coefficients > 0.514 P < 0.05

[c] = Correlation coefficients > 0.304 P < 0.05

n = number of animals

Table 3.5 Least squares means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily dry matter intake (kg) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2 x 6		7 x 12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	16.6	0.27	19.1	0.33	19.4	0.34	18.3	0.31	18.4	0.26
Parity											
2	26	16.3	0.46	18.5	0.56	18.4	0.59	18.2	0.53	17.9	0.45
3	34	16.2	0.36	19.0	0.45	19.4	0.46	18.1	0.41	18.2	0.35
4	25	17.0	0.38	19.7	0.47	19.9	0.49	18.5	0.44	18.8	0.37
5	30	16.8	0.34	19.4	0.45	19.7	0.47	18.3	0.42	18.7	0.36
R^2		1.5		2.3		2.6		2.0		1.5	
Condition Score Groups											
1	65	17.6[a]	0.29	20.7[a]	0.36	20.1	0.37	18.1	0.33	18.9	0.29
2	26	17.2[a]	0.37	19.6[a]	0.44	19.5	0.45	18.3	0.41	18.7	0.35
3	24	15.0	0.65	17.7[b]	0.80	18.6	0.83	18.3	0.74	17.6	0.63
R^2		5.6		5.8		3.0		1.8		3.4	
Weight change (b,SE)	115	0.2042	0.0278**	0.1720	0.0561*	0.1244	0.0646	0.0995	0.0567	0.2496	0.0803
R^2		19.4		4.7		5.8		1.5		4.4	
Calving liveweight (b,SE)	115	0.00747*	0.00243**	0.00586	0.00296*	0.00894	0.00304**	0.00936	0.00272**	0.00827	0.00233**
R^2		3.4		4.4		5.2		5.8		4.8	

abcd Different superscripts in column indicate significant difference $P < 0.05$

* $P < 0.05$, ** $P < 0.01$

Table 3.6 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily dry matter intake (kg) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b, SE)	75	0.0615	0.0440	0.1553	0.0776*	0.1774	0.0814*	0.2838	0.1040*	0.1493	0.1136
R^2		0.8		1.9		3.0		5.7		0.9	
Calving liveweight (b, SE)	75	0.0099	0.0039*	0.0136	0.0046**	0.0092	0.0044*	0.0065	0.0047	0.0102	0.0386*
R^2		2.3		3.1		1.6		1.0		2.4	
Calving condition score (b, SE)	75	-1.528	0.715*	-2.160	0.853*	-0.626	0.833	-0.851	0.872	-1.204	0.707
R^2		1.1		2.4		0.6		0.4		1.5	
Parity Groups:											
1a	24	14.6[a]	0.26	16.7[a]	0.30	17.2[a]	0.32	16.8[a]	0.34	16.4[a]	0.26
1b	25	16.2[b]	0.26	18.1[b]	0.30	18.3[b]	0.31	17.4[b]	0.33	17.6[b]	0.26
2	14	19.2[c]	0.35	20.3[c]	0.40	19.5[c]	0.43	17.7[b]	0.45	19.2[c]	0.35
3	12	19.2[c]	0.36	21.7[d]	0.42	21.0[d]	0.44	19.8[c]	0.47	20.4[d]	0.36
All	75	16.7	0.16	18.6	0.18	18.6	0.19	17.7	0.20	18.0	0.16
Level of significance		***		***		***		***		***	

abcd Different superscripts in column indicate significant difference $P < 0.05$

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

explained 48.0-74.9, 42.4-66.4 and 37.6-64.3% of the total variation in the same traits respectively for Trial 2 (Table 3.2). The effectiveness of the models in explaining variation in DMI declined as lactation progressed.

The corresponding least squares means for these traits in Trial 1 are presented in Table 3.5 and Appendix Tables A.1 to A.3. For Trial 2, the unadjusted parity group means and least squares means for these traits are given in Table 3.6 and Appendix Tables A.5 to A.7.

Year of calving, as would be expected, was a most important factor influencing DMI, accounting for as much as 4.2-11.9% units of the total variation in this trait for results of Trial 1 (Appendix Table A.1). Significant ($P < 0.05$) year differences in DMI, maximum DMI, DMI% and $DMI/W^{0.75}$ in most lactation stages were due to low intakes of year 3 animals compared to other years. In years 1, 2 and 4 intakes of dry matter were similar over the experimental period even though DMI of year 1 animals was significantly low ($P < 0.05$) in lactation stages 1 and 2.

Month of calving tended to be an important factor affecting DMI in later parts of the experiment. Thus Trial 1 cows calving in September had significantly ($P < 0.05$) higher DMI in lactation stages 3 and 4 whereas November-December calvers had low DMI during these lactation stages. This trend in intakes was not present in DMI% and $DMI/W^{0.75}$ (Appendix Tables A.1-A.3).

In Trial 2, on the other hand, month of calving was not an important factor influencing any descriptors of dry matter intake. Month of calving, however, tended to account for a higher proportion of the total

variation in DMI in lactation stages 3 and 4 than other lactation stages (Appendix Table A.5).

Parity was not an important factor influencing DMI after adjustment for differences in environmental and animal factors for Trial 1. This accounted for only 1.5-2.6% of the total variation in DMI in various lactation stages (Table 3.5). The trend was, however, for higher feed intakes as cows matured (Parity 2-4). This pattern of DMI between parities held for DMI% and DMI/$W^{0.75}$ (Appendix Tables A.2 and A.3).

For Trial 2, both the least squares means and unadjusted parity group means for dry matter intake traits are presented. This is because least squares means may have no biological meaning for comparing cows with heifers (due to adjustment to similar liveweight) but are biologically useful for comparing within heifer groups or cow groups. Adjustment of dry matter intake traits for differences in environmental and animal factors failed to remove parity differences in these traits in most lactation stages (Appendix Tables A.5 to A.7). Thus year 5 heifers ate significantly ($P < 0.05$) more food (0.6-1.6 kg DM/day) than year 4 heifers. Differences between the two groups remained when DMI was expressed as DMI% or DMI/$W^{0.75}$. Also, as was expected, 2nd parity cows ate less food ($P < 0.05$) than older cows. When intake was expressed as DMI, DMI% and DMI/$W^{0.75}$ for the unadjusted means (Table 3.6) heifers ate less food ($P < 0.05$) than cows. These differences between parity groups in DMI (unadjusted means) are illustrated in Figure 3.1. Heifer groups tended to have flatter feed intake curves and reached maximum intake later than cows during the experiment. Differences between heifer and cow groups in DMI, however, declined with advancing lactation. Thus, for example, heifers (year 4) ate 4.6 kg

DM/day in lactation stage 1 but only 0.9 kg DM/day in lactation stage 4 less food than when they calved as 2nd parity cows. Regression coefficients indicate that these differences between the same animal as a heifer and as a cow was 28.0% in lactation stage 1 but 2.5% in lactation stage 4 (Table 3.4). This is reflected in the inconsistent correlation coefficients (in different lactation stages) between DMI in the same period of lactation of the same animal as a heifer and as a 2nd parity cow; this was 0.14 in lactation stage 1, but 0.66 in lactation stage 4.

The results from Trial 1 showed a significant ($P < 0.01$) interaction between milk yield (MY) groups and calving condition score (CS) groups (see Chapter 2 for groupings) on DMI in lactation stage 1, but not DMI% or DMI/$W^{0.75}$. Least squares means of DMI for cows calving in different condition score groups and classified into different milk yield groups are given in Table 3.7.

Table 3.7 Least squares means of daily dry matter intake of cows calving in different condition score groups and classified into different milk yield groups - TRIAL 1

	MILK YIELD GROUP								
FACTOR	**1**			**2**			**3**		
Calving Condition Score Group	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
1	16.2	0.49	10	18.0	0.44	24	18.5	0.31	31
2	16.5	0.78	3	16.7	0.48	14	18.4	0.49	9
3	10.3	1.67	3	16.4	0.60	7	18.1	0.48	14

Within a CS group DMI increased with increasing daily milk yield in lactation week 2. Within each MY group DMI tended to decline with increasing CS, however MY 1 animals had their highest feed intakes at CS 3.0-3.5 (Group 2). Due to few animals in some CS x MY classes,

individual class regressions of DMI on CS for each MY group were estimated and tested for heterogeneity. This was significant ($P < 0.05$). The slopes of the regressions were [b ± standard error (SE)] -2.736** ± 0.737; -1.426* ± 0.565; -0.561 ± 0.533 kg per unit CS for MY 1, 2 and 3 respectively.

Where ** = $P < 0.01$ and * = $P < 0.05$. Quadratic regression coefficients were found not to be different from zero. Also individual MY class regressions of DMI% and DMI/$W^{0.75}$ were found to be parallel but not coincidental.

As would be expected, all DMI descriptors increased significantly ($P < 0.01$) with increasing daily milk yield in lactation week 2 for both trials. For example, in Trial 1, differences between MY 1 and MY 3 (high yielders) animals in DMI was 12.0% in lactation stage 1 but 6.0% in lactation stage 4 and 11.0% over weeks 2-24 of lactation. These DMI differences are consistent with the DMI patterns (unadjusted means) from lactation weeks 2-24 illustrated in Figure 3.2.

Similarly, in Trial 2 a 1 kg increase in daily milk yield in lactation week 2 was associated with 0.05-0.14 kg/day increase in DMI (Appendix Table A.5). These regression coefficients tended to decline with advancing lactation, indicating a decreasing influence of this factor.

After the MY x CS interaction on DMI in lactation stage 1 increasing CS depressed ($P < 0.05$) DMI in lactation stage 2 and DMI% and DMI/$W^{0.75}$ in lactation stage 1 for the results of Trial 1. Thus CS 1 animals ate 17.0% more DMI in lactation stage 1 but 1.0% less DMI in lactation stage 4 than CS 3 (fat) animals (Table 3.5). There was, however, very little difference between CS groups in the unadjusted

means for DMI shown in Figure 3.3. This is an indication of the confounding effects of other factors influencing DMI.

The results from Trial 2 also demonstrated that increasing CS depressed ($P < 0.05$) DMI and DMI/$W^{0.75}$ in lactation stages 1 and 2 and maximum DMI (Table 3.6 and Appendix Tables A.6 and A.8). A unit increase in CS in Trial 2 was associated with a decline in DMI by 0.6-2.2 kg/day (in various stages of lactation) and maximum DMI by 2.3 kg/day, using the Langhill complete diet.

Weekly weight change had a positive association with DMI in both trials. It was, however, surprisingly associated positively with DMI% and DMI/$W^{0.75}$ in Trial 1 but negatively with these same traits in Trial 2.

For Trial 1, the relationship between weekly weight change and DMI was only significant ($P < 0.05$) in lactation stages 1, 2 and over stages 1-4. Weekly weight change accounted for 4.4-19.4% of the total variation in DMI in these stages of lactation. Also, a 1 kg increase in weekly weight change was equivalent to 0.17-0.25 kg/day increase in DMI (Table 3.5). Weekly weight change in lactation weeks 2-6 had a significant ($P < 0.01$) negative association with week of maximum DMI, but a non-significant positive relationship with maximum DMI (Appendix Table A.4). The significant ($P < 0.05$) relationship between weight change and DMI% or DMI/$W^{0.75}$ in lactation weeks 2-6 (stage 1) was influenced by the daily milk yield in lactation week 2. The individual MY group regressions of DMI% and DMI/$W^{0.75}$ on weekly weight change were ($b \pm SE$):

DMI%

$0.0366^{**} \pm 0.0113$; 0.0035 ± 0.0083; $0.0268^{**} \pm 0.0079$ % units/kg weekly weight change

2.076** ± 0.577; 0.347 ± 0.423; 1.478** ± 0.406 g/kg weekly weight change for MY 1, 2 and 3 respectively

Where ** = $P < 0.01$

Likewise, the results of Trial 2 show that weekly weight change was significantly associated with DMI in lactation stages 2-4 (weeks 7-24). It was, however, negatively ($P < 0.05$) related to week of maximum DMI (Appendix Table A.8). The association of this variable with DMI% and $DMI/W^{0.75}$ was not significant. A noticeable feature of the results from Trial 2 was the increasing influence of weekly weight change on DMI with advancing lactation (this is the opposite of results from Trial 1). However, weekly weight change only explained 1.9-5.7% of the total variation in DMI in these stages of lactation (Table 3.6). It is significant to note that a 1 kg increase in weekly weight change was associated with 0.15-0.28 kg/day increase in DMI for Trial 2.

Calving liveweight, as expected, was an important factor affecting positively DMI, but negatively DMI% and $DMI/W^{0.75}$ in both trials of this investigation (Figures 3.6-3.8). It explained 3.4-5.8 and 1.0-3.1% of the total variation in DMI for Trials 1 and 2 respectively. Noticeably, the effect of calving liveweight on DMI tended to increase in Trial 1 but decline in Trial 2 as lactation progressed (Tables 3.5 and 3.6). The slopes ($P < 0.05$) of the regression of DMI on calving liveweight were 6-9 g/kg in Trial 1 but 6-14 g/kg in Trial 2.

3.2 Discussion

3.2.1 GENERAL

The aim of the present study was to investigate the causes of variation

Figure 3.1 : Mean dry matter intakes(kg/day) between weeks 2 and 24 of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(-),Second calvers(O),YR4 Heifers(+),YR5 Heifers(x).

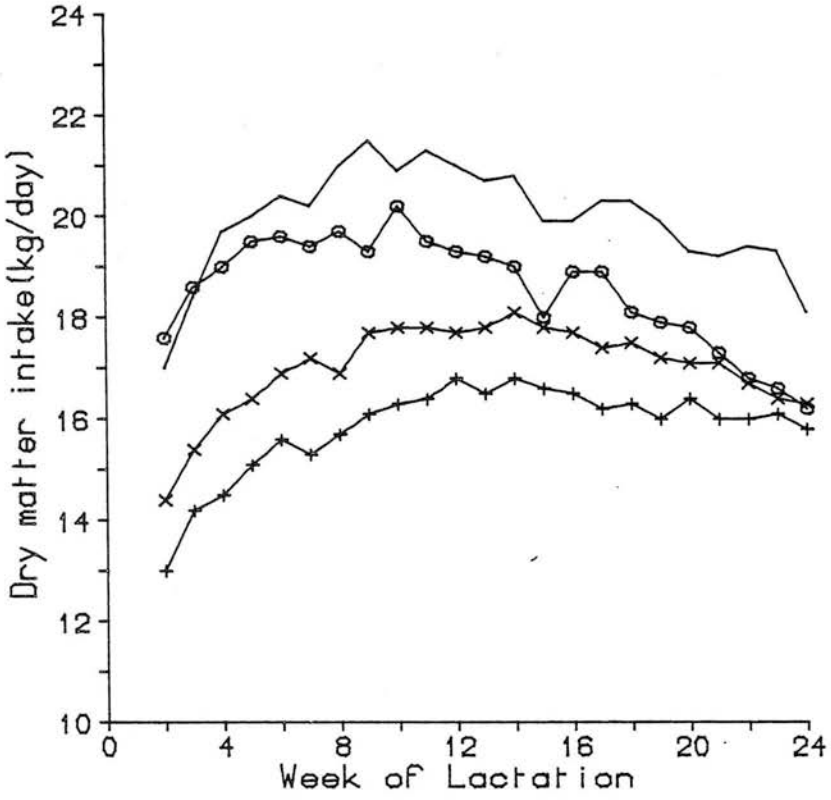


Figure 3.2 : Mean dry matter intakes(kg/day) between weeks 2 and 24 of lactation for 3 milk yield groups :MY1(low,X),MY2(medium,*),MY3(high,o).

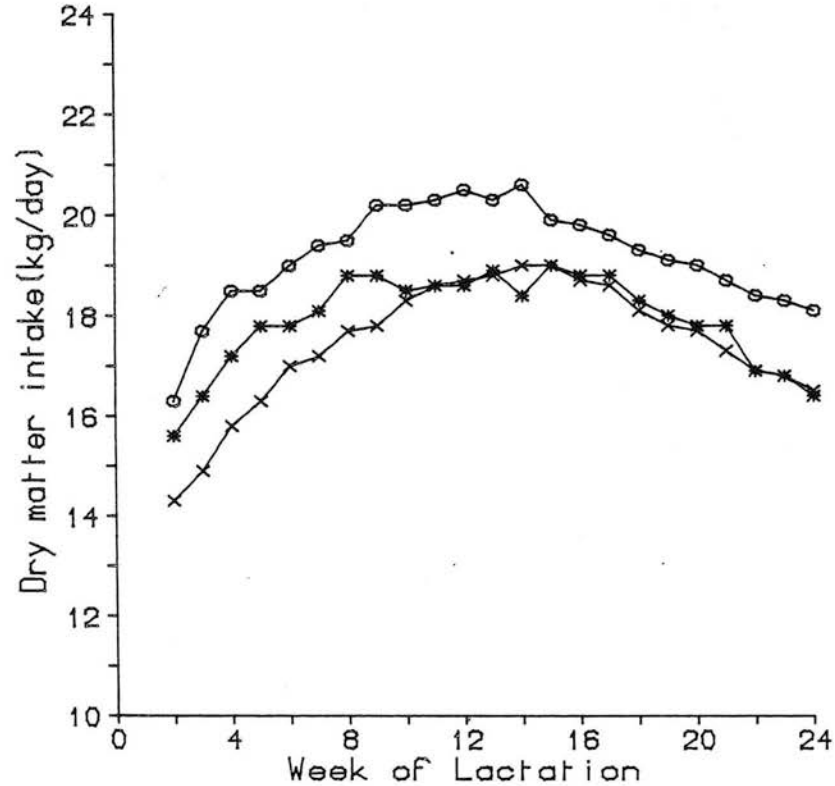


Figure 3.3 : Mean dry matter intakes(kg/day) between weeks 2 and 24 of lactation for 3 condition score groups :CS1(thin,X),CS2(medium,*),CS3(fat,o).

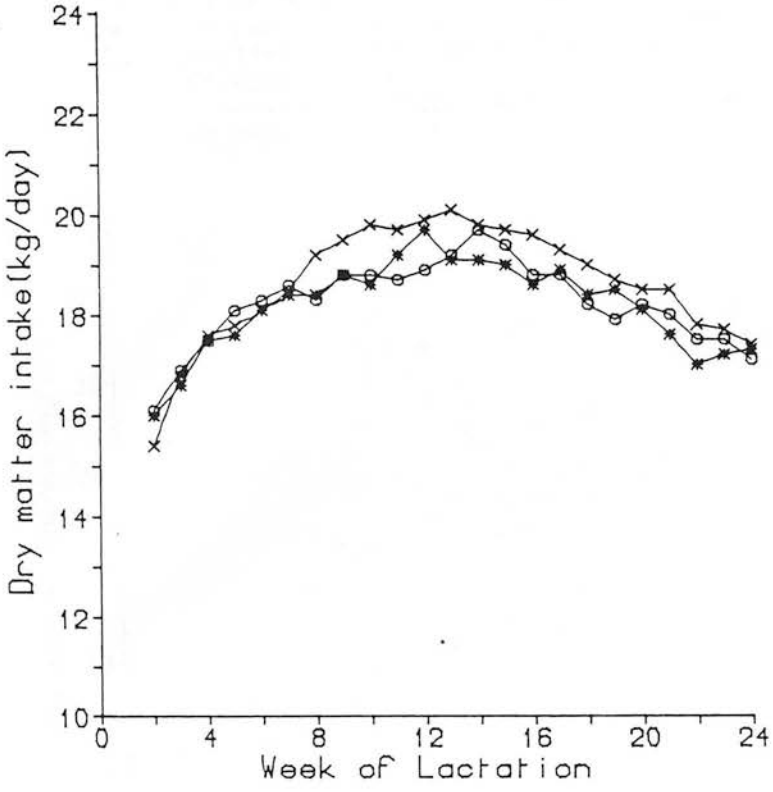


Figure 3.4: Relationship between dry matter intake (Y,kg/day) and milk yield(X,kg/day) over 2 to 24 weeks of lactation:
COWS O--O(Y=12.76(SE,1.12)+0.2212(SE,0.0392)X; R^2=19.1%,RSD=1.839);
HEIFERS +--+(Y=11.61(SE,1.19)+0.2351(SE,0.0412)X; R^2=28.2%,RSD=1.046)

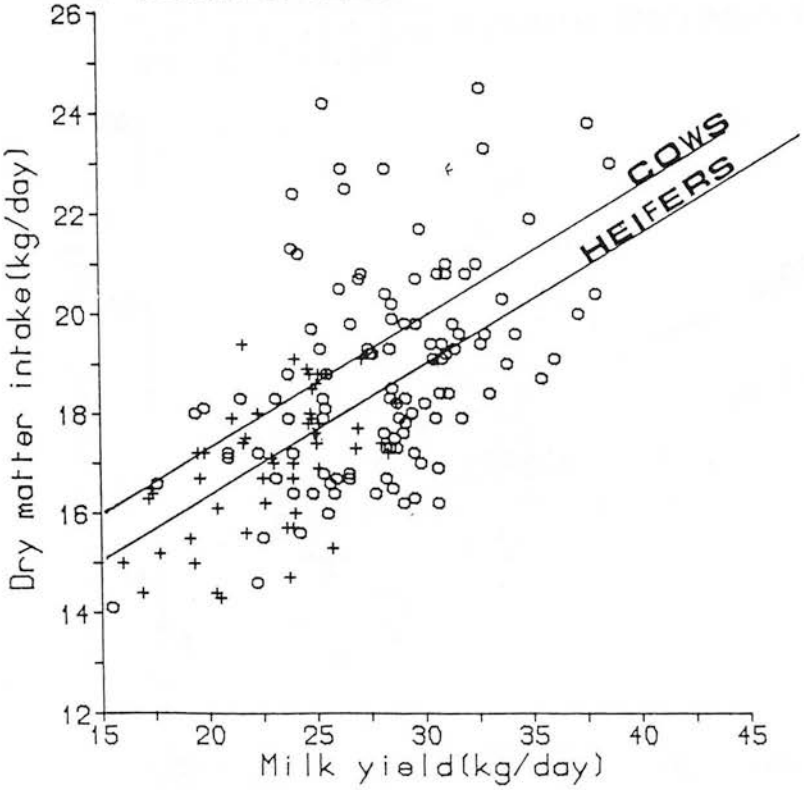


Figure 3.5: Relationship between dry matter intake(Y,kg/day) and FCM yield(X,kg/day) over 2 to 24 weeks of lactation: COWS o--o(Y=13.21(SE,1.05)+0.1993(SE,0.0359)X; R^2=18.6%,RSD=1.845); HEIFERS +--+(Y=11.12(SE,0.994)+0.2453(SE,0.0412)X; R^2=40.8%,RSD=1.046)

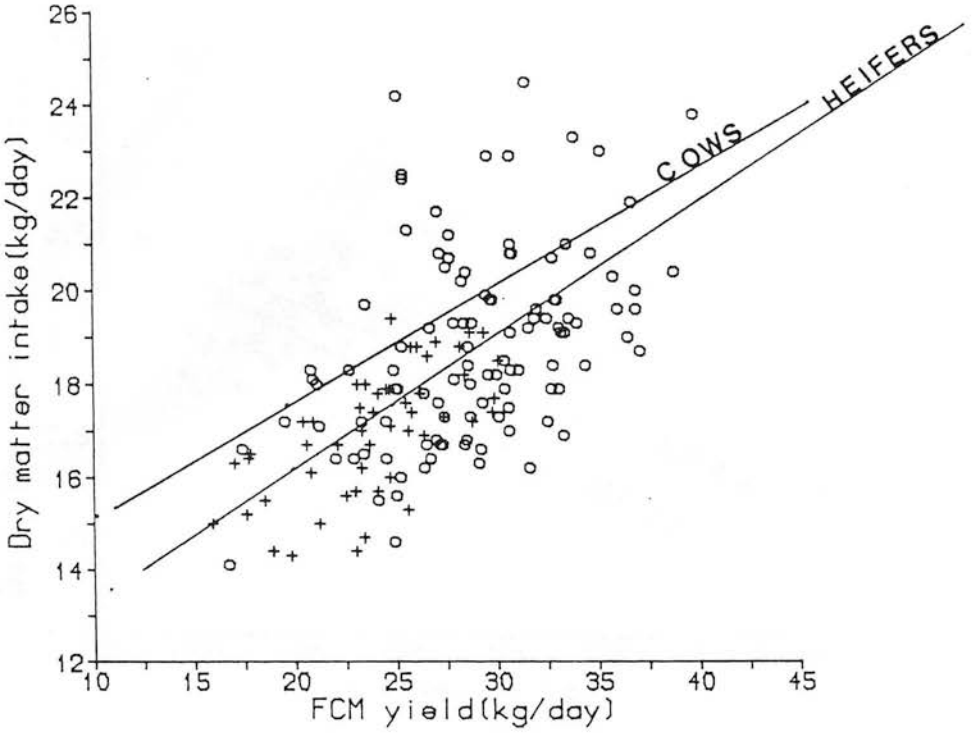


Figure 3.6: Relationship between dry matter intake(Y,kg/day) and live weight(X,kg) over 2 to 24 weeks of lactation: COWS o--o(Y=10.99(SE,1.82)+0.01256(SE,0.00284)X; R^2=19.0%,RSD=2.899); HEIFERS +--+(Y=13.85(SE,2.27)+0.00571(SE,1.39)X; R^2=1.8%,RSD=1.348)

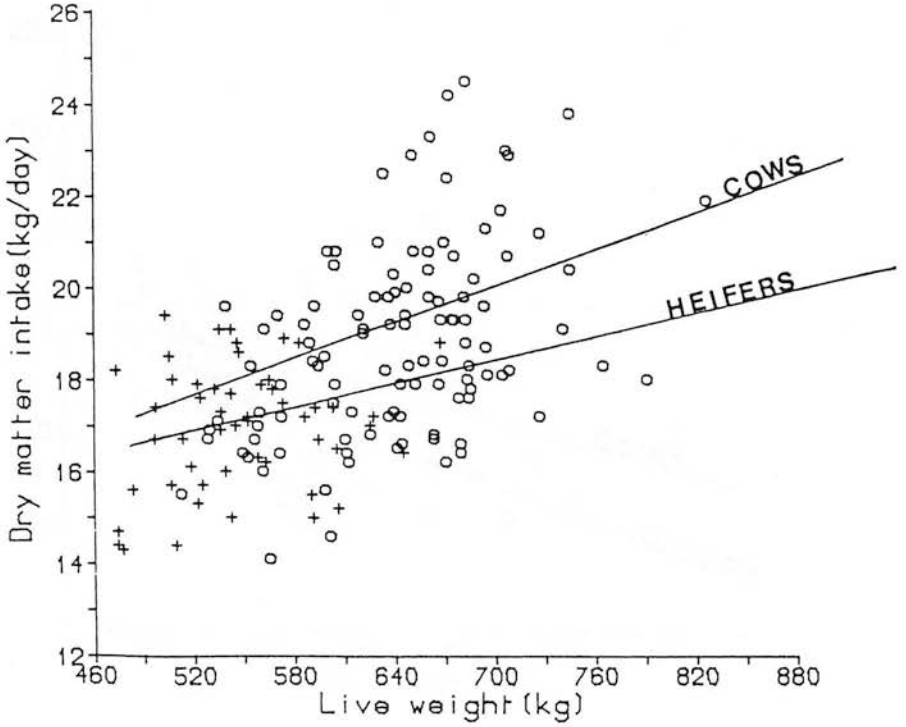


Figure 3.7: Relationship between daily dry matter intake (Y,% live weight) and live weight (X,kg) over 2 to 24 weeks of lactation: COWS o--o (Y=4.766 (SE,0.276)-0.00279 (SE,0.00043)X; R^2=23.8%, RSD=0.2899); HEIFERS +--+ (Y=5.564 (SE,0.423)-0.00447 (SE,0.00077)X; R^2=39.6%, RSD=0.2516)

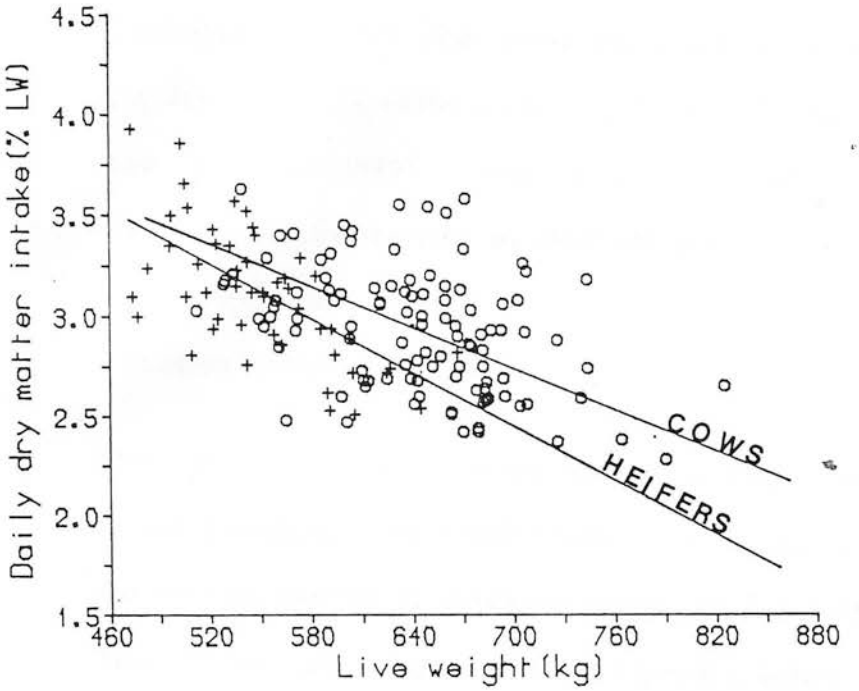
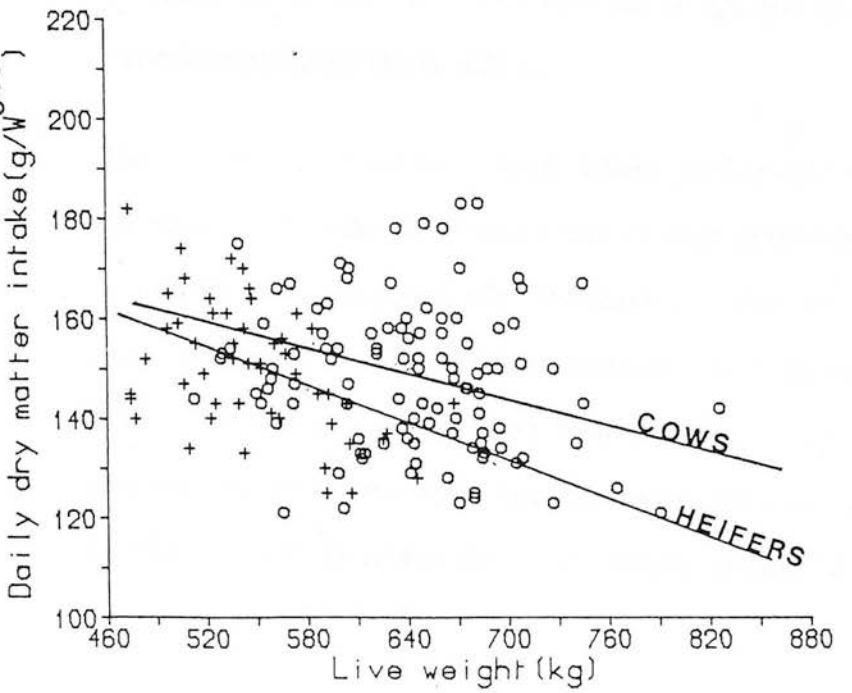


Figure 3.8: Relationship between daily dry matter intake (Y, g/$W^{0.75}$) and live weight-W (X,kg) over 2 to 24 weeks of lactation: COWS o--o (Y=198.7 (SE,14.2)-0.0761 (SE,0.0221)X; R^2=7.6%, RSD=14.90); HEIFERS +--+ (Y=226.3 (SE,19.3)-0.1394 (SE,0.0351)X; R^2=22.8%, RSD=11.48)



in DMI between animals of different milk production levels offered similar feed ad libitum. Each animal in the trial had therefore an equal opportunity to express potential for feed intake. The approach adopted in the present experiment to examine differences between animals in feed intake differs from other experiments reported in the literature (eg Johnson et al, 1966; Curran et al, 1970; Brown et al, 1977; Vadiveloo and Holmes, 1979). Most animal characteristics were selected immediately post-calving to estimate their influence on voluntary feed intake (VFI) and whether intake could be precisely predicted later in lactation by these factors.

Subclasses of animal characteristics were also selected based on reports in the literature. Frood and Croxton (1978) indicated higher milk yields for animals calving at condition score below 3.0 than above this level. Thus calving condition score classes (groups) below 3.0, between 3.0 and 3.5 and above 3.5 were chosen for Model 1 of Trial 1. Similarly, the work of Johnson (1977) and Strickland and Broster (1981) demonstrated that daily milk yield in lactation week 2 was a good indicator of the potential milk yield of the animal. Furthermore, milk yield in the first two weeks of lactation is used to block animals in groups in long-term nutritional experiments (Strickland, 1975).

The pattern of voluntary feed intake during lactation appears similar for most cows under different experimental conditions; being low in early lactation and progressively increasing daily to reach maximum in lactation week 12 (Journet and Remond, 1976; Broster et al, 1982). The level and rate of DMI increase from calving to time of maximum intake are influenced by management practices and environmental factors and by characteristics of the diet and animals (Bines, 1979; Garnsworthy and

Topps, 1982b; Bertillson and Burstedt, 1983; Phipps et al, 1984b).

The present results tended to follow this general pattern of DMI. Intakes of dry matter progressively increased from calving reaching a maximum value of 20.6-22.6 kg/day at week 15-16 of lactation. Over weeks 2-24 daily DMI was 16.4-17.6 (heifers) and 19.4 kg (cows). These results are similar to 17.4 and 18.3 kg/day DMI reported by Ostergaard (1979) for heifers and cows respectively over lactation weeks 1-24, and the 22.2-22.5 kg/day maximum DMI observed by Garnsworthy and Topps (1982b). The average DMI of the present results is close to 18 kg estimated from the equation of MAFF (1975) (DMI = 0.025 LW + 0.1 MY, 1975) for a 600 kg cow producing 30 kg milk/day.

When DMI was expressed as DMI% in lactation weeks 2-6 the 2.78-3.04 was slightly lower than 2.85-3.38 observed by Coppock et al (1974) and Bertilsson and Burstedt (1983). These differences were due to heavier animals used in the present experiment compared to the other experiments (595-600 vs 522-597 kg); milk yields were similar.

Expressing DMI as DMI/$W^{0.75}$ resulted in a maximum daily intake of 178 g and a daily intake of 149 (Trial 1) to 154 g (Trial 2) over lactation weeks 2-24. These values are higher than the maximum intake of 123-141 g reported by ARC (1980) from different sources and the daily intake of 135 g observed by Greenhalgh and McDonald (1978) for cows producing about 5000 kg FCM in 305 days of lactation. The high DMI values of the present experiment were probably due to high milk yields of the animals (6600-7200 kg FCM in 305 days of lactation). These results suggest that reporting DMI as DMI% or DMI/$W^{0.75}$ without providing average milk production levels and liveweights of the animals is not meaningful.

In contrast to other reports, the animals in the present investigation were very variable in unadjusted DMI. Oldenbroek and Van Eldik (1980) and Korver (1982) observed 4.6-7.7% coefficient of variation (CV) in DMI. The 12.6-13.6% CV over weeks 2-24 of lactation in the present study agrees with the 15% reported by Broster et al (1980). The large variation in this experiment would therefore tend to disagree with the report of Wiktorsson and Bengtisson (1973) that there is less variation in feed intake when cows are fed blended diets. Perhaps the wide range of animals of different genetic potentials, sizes and ages used in the present report was responsible for the high between animal variation.

In line with previous studies, animals were more variable in DMI in early lactation than in later lactation (Coppock et al, 1974; Bieri et al, 1982; Korver, 1982). Differences between animals in body condition at calving was partially responsible for this large variation in early lactation. This is supported by increasing standard errors in DMI with increasing condition scores observed in Table 3.7. Physical and physiological effects of body condition on DMI have been explained by Bines (1976) and Campling (1980). Expressing DMI as DMI% and DMI/$W^{0.75}$ also only reduced CV in DMI by 1-2% (Tables 3.1 and 3.2).

This investigation demonstrated that DMI in early or other stages of lactation was not a good index for predicting DMI in other periods of lactation. This is consistent with the findings of Ostergaard (1979), Campling (1980) and Korver (1982). The present results also suggest that DMI in one stage of lactation was not a good index for predicting the feed intake by the same cow in the same stage of the next lactation. These correlations undoubtedly depend on uniformity of diet composition fed throughout the experimental period and also the calving body

condition of animals in the different lactations. For example, increasing concentrate to forage ratio increases DMI and vice versa (Coppock et al, 1974; Phipps et al, 1984b). Also the level and daily increase in DMI from calving to time of maximum intake is depressed by increasing body fatness at calving (Garnsworthy and Topps, 1982b).

The present results showed that 25-59% of the variation in DMI could not be explained by environmental factors and early lactation animal characteristics. This suggests that

(1) the factors are not linearly related to DMI (quadratic relationships were also found to be non-significant);

(2) the relationship between the factors and DMI are not constant across cows;

(3) errors of measurement are large and therefore quantities of each factor are not directly proportional to the measurement recorded to represent them. (Emmans and Neilson, 1984).

These results are, however, similar to reports of Coppock et al (1974), Journet and Remond (1976) and Bieri et al (1982) using animal characteristics within the lactation period as factors. For example, Bieri et al (1982) observed that a model containing breed, number and stage of lactation, pregnancy, season, milk yield and liveweight explained 49 and 68% of the variation in forage and total feed intakes respectively. The literature and the present results would tend to suggest that animal factors alone can explain up to 75% of the total variation in VFI. These reports do not indicate if there is further room for improvement of VFI prediction equations based on only animal factors.

Of the factors studied in Trial 1 daily milk yield in lactation week 2 and

year of calving had the most effect on feed intake in all lactation stages (Appendix Table A.1). Weekly weight change and calving condition score were only important factors in lactation stages 1 and 2. Including heifers with cows (Trial 2) made parity the most important factor rather than daily milk yield in lactation week 2 (Appendix Table A.5), reflecting the high positive correlation between these two factors. Dropping liveweight, parity and milk yield in lactation week 2 one at a time from the models resulted in only small decreases in R^2 (the total variance explained by the model). This suggests inter-dependence of these factors. This does not, however, affect the precision of prediction equations, although the coefficients have no predictive value outside the models (Draper and Smith, 1981).

3.2.2 EFFECTS OF DIFFERENT FACTORS ON VOLUNTARY FEED INTAKE

3.2.2.1 Environmental Effects

The objective of the investigation was to provide similar quality feed (similar M/D and crude protein) to allow a similar DMI across years. The present results would tend to indicate that this objective was not successful as years accounted for 4.2-11.9% of total variation in DMI (Appendix Table A.1). Differences in intake between years of calving could be due to differences in forage quality for differences between years in incidence of disease was small (Appendix Table A.2.3.).The high ammonia-N (126 g/kg total N) of year 1 silage and low dry matter of the mixed diet (Appendix Figure A.4) of year 3 were probably responsible for the low intakes of these years, arguments used by Wilkins (1974, 1982), McCullough (1973) and Kroll (1983).

It would also seem from the present experiment that increasing

maintenance requirements (borne out by lack of monthly influence on DMI/$W^{0.75}$) and the system of concentrate allocation probably contributed to the significant effect of month of calving on DMI in lactation stages 3 and 4. Under the present system concentrate in the diet mix is gradually reduced after 100 days of lactation until the end of the winter period. Cows calving in the autumn are therefore fed diets high in energy for the first 4 months whereas those calving in November-December enter the experiment at a time when diet energy would have started to decline. Low M/D diets can depress feed intake (Phipps et al, 1984b). Also in years 1-3 second cut silages (normally of low quality) were fed in later parts of the experiment. Perhaps this caused some differences between months in intakes (Wilkins, 1974, 1982).

The present analysis therefore suggests that environmental factors (years and months of calving) must be included in the estimation of prediction equations from pooled data of the first 4 years of the experiment.

3.2.2.2 Effects of Parity

Feed intake is reported to increase from 1st parity to 4th parity (Bieri et al, 1982). It was only in Trial 2 where heifers were present that this trend was noted. Differences between parity groups in Trial 2 could not be attributed to animal differences including month of calving, calving liveweight and condition score, milk yield in lactation week 2 and weekly weight change. Reticulo-rumen capacity could explain some of the differences between cows and heifers in DMI. Reticulo-rumen capacity is thought, however, not to be an important factor influencing intake of highly digestible diets (Bines, 1979). Possibly this argument holds for experimental conditions using only cows. For example, Bines (1976) observed that differences between heifers and cows in digestible energy

intake declined from about 17-10% as the concentrate in the diet was increased from 60-90%; suggesting some influence of reticulo-rumen capacity. Journet et al, 1965, cited by Bines (1979), noted an increase in feed intake from 1st to 2nd lactation independent of greater body size and milk yield. This was, however, attributed to the considerable increase in the requirements of the cow at first calving and the progressive adaptation of appetite to these requirements between 1st and 2nd lactation. In the present experiment there was a 17% difference in feed intake between the same animal as a heifer and as a 2nd parity cow. This is similar to 11-17% reported by Oldenbroek (1984b).

DMI expressed as DMI% or DMI/$W^{0.75}$ did not alter these differences between parity groups in feed intake (Appendix Tables A.6 and A.7). This is in line with the findings of Donker et al (1983) but disagrees with those of Ostegaard (1979), Strickland and Broster (1981) and Brown et al (1983). Since weight of animals is influenced by both skeletal size and fatness, the confounding effects of body fatness were undoubtedly responsible for some observed differences between experiments.

Heifers in the present investigation had flatter DMI curves than cows (Figure 3.1) in agreement with reports of Ostergaard (1979). High nutrient demand of milk production and growth of heifers during lactation and/or the flatter milk yield curves of heifers than cows (Broster and Broster, 1984) could account for this pattern of DMI.

3.2.2.3 Milk Yield (MY) x Calving Condition Score Interaction

It is evident from the present experiment that high yielding cows in lactation week 2 do not exhibit similar relationships between condition score and DMI in weeks 2-6 of lactation as low yielding cows. One must

be cautious in drawing conclusions on the effects of a subjective measure as condition score on other variables, even if this was determined by one operator. The wrong condition scoring of a few animals can lead to misleading results. Furthermore, similar observations have not previously been reported. Neilson et al (1983), however, using the data of years 1 and 2 of this investigation, observed an interaction between backfat area and milk yield (lactation weeks 1-26 average yield) on milk energy ÷ food energy intake.

Differences between low and high yielding cows on the effect of body fatness on DMI suggests two hypotheses:

(1) Body reserves are preferentially utilized for milk production and the rest of potential nutrient requirements made up from dietary sources.

(2) The regulatory mechanisms influencing voluntary feed intake is different between high and low yielding cows during lactation.

The latter appears more plausible. Evidence, for example, indicates that the changeover point of physical and metabolic regulation of feed intake is not static but is influenced by energy requirements of the animal (Baumgardt, 1970). A similar regulatory mechanism could be involved in the present interaction.

The lack of significant interaction of milk yield and calving condition score on DMI in other stages of lactation tends to suggest that by lactation week 7 milk yield group 1 animals (fat), through body fat mobilization, declined in BS close to their optimum DMI condition score levels (3.0-3.5 - Table 3.7). These results also suggest that milk yield is the principal determinant of DMI rather than the converse in early lactation. This is consistent with deductions of Monterio (1972) and

Bryant (Personal Communications). It is doubtful if this relationship holds later in lactation due to observed declining correlations between milk yield and DMI with advancing lactation (Appendix Chapter 4).

3.2.2.4 Main Effect of Milk Yield

Studies by Johnson (1977, 1979) and Strickland and Broster (1981) have shown that milk yield in lactation week 2 is a good index for defining milk yield potential. Wiktorsson (1980) and Davey et al (1983), likewise, demonstrated a positive association between milk yield potential (measured as milk yield in 305 days of lactation and breeding index, respectively) and feed intake.

The expectation of the present study was that animals with higher outputs of milk in lactation week 2 would eat more food during the experiment. The results are consistent with this expectation. The results, however, suggest that animals blocked according to milk yield recorded for only one day in lactation week 2 is not always an efficient method of establishing significant differences between animals in VFI. This is borne out by lack of significant difference between milk yield groups 1 and 2 animals (milk yield difference of 7 kg/day in lactation week 2) in DMI after lactation week 12 (Appendix Table A.1). Even differences between milk yield groups 1 and 3 animals (milk yield difference = 12.8 kg/day) declined from 21.7% (lactation weeks 2-6) to 5.8% (lactation weeks 19-24).

Similar results are not available in the literature for direct comparisons. Also these differences cannot be explained by differences in milk yield or FCM (see Figures 4.5 and 4.6, Chapter 4). The results are, however, consistent with the observation that, though feed intake increases with

energy requirements of the animal, the relationship between milk yield and DMI over long periods of time is moderate (r = 0.6) due to the ability of the dairy cow to mobilize body fat for milk production (Journet and Remond, 1976; Bines, 1979). This large variation in DMI within milk yield groups was demonstrated by Wiktorsson (1980) and in the present investigation (Figures 3.4 and 3.5).

3.2.2.5 Main Effects of Calving Condition Score (CS)

Both trials of the present investigation demonstrated unequivocally a negative relationship between body fatness and DMI. This was, however, only significant between lactation weeks 2-12. Expressing DMI as DMI% or $DMI/W^{0.75}$ did not influence the effect of CS on DMI. The present results, in general, are consistent with the suggestion that gradual increase in feed intake after calving is due to time taken for abdominal fat to be mobilized before the rumen can expand to its maximum size (Bines, 1976). The greater effectiveness of CS on DMI descriptors in lactation weeks 7-12 than weeks 2-6, however, suggests that other factors other than physical limitations of abdominal fat exerted some influence in this pattern of intake. It has been suggested that blood metabolites and hormones resulting from mobilization of body fat are involved (Journet and Remond, 1976). Their mode of action is, however, not clear. Negative correlations between blood-free fatty acid levels and DMI in the first 16 weeks of lactation and the faster decline of these fatty acid levels for thin than fat cows noted by Garnsworthy and Topps (1982a) could explain the action of CS on DMI in the two stages of lactation of the present investigation. It is significant to note that Forbes (1983) from his computer model on feed intake suggested that both metabolic and physical attributes of body fatness influence

voluntary feed intake.

The present results are in agreement with previous workers in that where differences between cows in body fatness are large, fat cows eat less food than thin ones (Lodge et al, 1975; Land and Leaver, 1981; Grainger et al, 1982; Garnsworthy and Garner, 1985). Fat cows also have a slow rise in feed and therefore reach peak intake later than thin cows (Garnsworthy and Topps, 1982b).

One could naively speculate that the inverse relationship between calving condition score and feed intake is more the result of feeding high energy diets to a fat animal whose limiting nutrient resource is not energy but some other nutrient such as protein. Increasing this limiting resource in relation to energy would be expected to result in increased feed intake. Feed intake is reported to increase with increasing protein content of isoenergetic diets in early lactation (Macleod et al, 1984).

These results suggest that to reduce the lag between feed intake and feed requirements, without resorting to very high energy diets, cows should calve thin (not above 3.0 units of body condition score).

3.2.2.6 Effect of Calving Liveweight (LW)

In line with previous work the present experiment has demonstrated a positive effect of calving body weight on DMI (Miller et al, 1973; Grieve et al, 1976; Ostergaard, 1979; Donker et al, 1983). This relationship is, however, not exactly proportional to liveweight. Therefore, expressing DMI as DMI% or DMI/$W^{0.75}$ tends to favour small cows in intake (see Figures 3.6 to 3.8), even when variations in milk yield are accounted for (Tables 3.5 and 3.6). This experiment and other reports (Weston, 1982) therefore cast doubt on the practice of reporting DMI data of dairy cows

in terms of DMI% or DMI/$W^{0.75}$ (ARC, 1980) for the same breed. It seems that DMI would probably be related closely with metabolic weight ($W^{0.75}$) under conditions of limited time of access to feed. Under these conditions rate of removal of metabolites will be a factor controlling intake (Bines, 1979).

The regression coefficients of DMI on calving liveweight was small in Trial 1 (6-9 g per kg increase in calving liveweight) where calving liveweight was less variable (CV = 10%). These coefficients (7-14 g) were moderate in Trial 2 where calving liveweight was more variable (CV = 12%). Ostergaard (1979) had previously reported 2-7 g per kg weight change. These coefficients cannot be regarded as absolute. This is because weight (or change in weight) from animal to animal represents large differences in body condition and gut fill (Bines, 1976, 1979). This is possibly reflected in the decline in Trial 2 but increase in Trial 1 of effectiveness of LW on DMI as lactation progressed. The relationship in Trial 2 can be explained. Most small animals would be heifers with low intakes in early lactation resulting in large differences due to liveweight. However, as lactation progressed feed intake of heifers increased, reducing the large variation due to liveweight. The relationships in Trial 1 are difficult to interpret. If, however, the gradual hypertrophy of the gut and/or physical removal of abdominal fat, as suggested by Forbes (1980) and Bines (1976), is more rapid in small than large cows, this could explain the increasing feed intake differences between the two size groups as lactation progressed.

3.2.2.7 Effect of Liveweight Change

The present results showed that increasing weekly liveweight change (LWC) was associated with increasing DMI irrespective of stage

or lactation or milk yield in lactation week 2. There was 0.10-0.24 and 0.06-0.28 kg/day increase in DMI for every kg increase in LWC for results of Trials 1 and 2 respectively (Tables 3.5 and 3.6). These coefficients declined in size for Trial 1 but increased in size for Trial 2 as lactation progressed. Furthermore, the coefficients in lactation stages 3 and 4 for Trial 1 and in lactation stage 1 for Trial 2 were not different from zero.

These results tend to suggest that there is a large between animal variation in the relationship between DMI and LWC. It was expected that all regression coefficients would be significant, but negative in early lactation (weeks 2-12) reflecting low feed intakes at this time and positive later in lactation, reflecting higher feed intakes then. Only the coefficients of week of maximum DMI with LWC (lactation weeks 2-6) were negative; in agreement with observations of Journet and Remond (1976) that animals during lactation continue to increase daily in feed intake as long as they lost weight. Differences between lactation stages and between the two trials in the level of statistical significance of the association between LWC and DMI are difficult to reconcile. These results are, however, consistent with other reports in the literature that these relationships have not always been significant. Curran et al (1970) found that LWC was significantly associated with DMI in lactation weeks 1-4 but not weeks 13-16. The results (Trial 2) are at variance with the observation of the same authors that declining standard deviations of LWC was associated with decreasing effectiveness of this term on DMI. These differences can be interpreted. Variations in size of LWC caused by differences between animals in gut fill and/or in composition of LWC were undoubtedly involved (Moe et al, 1971; Broster et al, 1980). In early

lactation, for Trial 1 (only cows), most cows would tend to mobilize body fat resulting in less variation in the magnitude of LWC, but with advancing lactation size of LWC would be more variable due to the proportion that is fat or protein and water as animals gained weight. The former interpretation will result in significant association between LWC and DMI but not the latter. Similarly, in Trial 2 (cows and heifers) cows because of their larger fat reserves would tend to mobilize more fat into LWC than heifers in early lactation causing significant variations in the size of LWC. Furthermore, in early lactation, LWC of heifers will be more influenced by gut fill, due to their low intakes at this time, than cows. With advancing lactation, however, the effect of gut fill would be minimised due to less variable feed intake, also both cows and heifers would be gaining weight resulting in less variation in magnitude of this trait. The latter interpretation would result in significant association between LWC and DMI but not the former.

The present coefficient, however, parallel the 0.14 kg/day observed by Johnson et al (1966) and 2.45 kg/day noted by Bines et al (1977) in weeks 1-16 of lactation. The confounding effects of gut fill on LWC and other factors included with LWC in regression analysis model could explain the large variation in the above coefficients. For example, the results of Bines et al (1977) had no measure of body condition; the results of Johnson et al (1966) and the present investigation had. It is interesting to note that all coefficients were positive, tending to support the contention of Bines (1979) that the use of LWC as independent variable to predict DMI has no biological significance. These positive coefficients are probably more a reflection of the partition of food into liveweight gain and milk yield described by Broster (1976). Broster's model

demonstrated an increased response in LWC with increasing feeding level.

3.3 Conclusion

The results showed that between animal variations in DMI declined as lactation progressed reaching minimum values in lactation stage 3; the stage of maximum feed intakes. Mean daily maximum DMI for the two trials ranged from 20.6-22.6 kg (3.50-3.62% or 178 g/$W^{0.75}$) and was achieved, on average, between lactation weeks 15-16. There was only a small reduction in between animal variation when DMI was expressed as DMI% or DMI/$W^{0.75}$. Correlations between DMI in one stage of lactation and the next stage of lactation declined as the time separating the two stages increased. Also, the within cow correlations between DMI in the same stage of lactation in consecutive lactations of the same cow were small in lactation weeks 2-6 but moderate in lactation weeks 19-24.

Environmental and animal (immediately post-partum) factors accounted for a large proportion of the variation in DMI in lactation stage 1 (R^2 = 60-74%). The effectiveness of these factors as predictor variables of DMI, however, declined as lactation progressed.

Calving condition score was negatively associated with DMI in early lactation (weeks 2-12), but was positively related to week of maximum DMI. The degree of this negative effect was influenced by the level of milk production in lactation week 2. The approach used in the present experiment gives no insight into the mechanisms involved in this interaction. The experiment, however, raised questions on appetite control to which basic physiological research can be applied; the relationship of body fatness and energy

requirements on VFI.

Daily milk yield in lactation week 2 was positively correlated with DMI, but at a declining rate with advancing lactation.

Calving LW was positively associated with DMI, but was negatively correlated with DMI% and DMI/$W^{0.75}$. LWC was also positively related to DMI (though not significantly in all lactation stages) irrespective of stage of lactation or the daily milk yield in lactation week 2.

Heifers ate 17% less food than cows over the experimental period. These differences were normally very high (28%) in early lactation (weeks 2-6). These differences remained when DMI was expressed as DMI% or DMI/$W^{0.75}$.

It is concluded that simple empirical relationships, using animal characteristics immediately post-partum as predictor variables, are not precise enough for predicting DMI, especially later in lactation. DMI in early lactation is not a good index for predicting DMI later in lactation. Furthermore, DMI in one lactation is not a good estimator of the DMI in the succeeding lactation. Variation between animals in milk yield and calving condition score are important factors related to variation between animals in VFI in lactation weeks 2-12. Milk yield is the main determinant of DMI rather than the converse in early lactation. Cows, therefore, for improved DMI in early lactation, should calve in a thin condition (not greater than 3.0 units of condition score). DMI is not directly proportional to LW, therefore expressing DMI as DMI% or DMI/$W^{0.75}$ favours small animals without any effect on the between animal variation in DMI. There is no advantage therefore to the use of DMI% or DMI/$W^{0.75}$ for dairy cattle of the same breed on ad libitum feeding. LWC is a useful independent variable for improving the precision of prediction of VFI, especially in early lactation.

This relationship, however, has no biological meaning. Very low feed intakes of heifers in early lactation underscore the need for heifers to be specially fed high energy diets at this time.

4 MILK PRODUCTION

4.1 Results

4.1.1 GENERAL

Tables 4.1 and 4.2 show means for milk production traits (daily and 305-day milk and fat corrected milk (FCM) yields, milk fat and milk protein contents) for Trials 1 and 2 respectively. Milk production traits varied extensively among cows. Generally, daily milk and FCM yields increased with time reaching maximum levels in lactation stage 2 (weeks 7-12) and lactation stage 1 (weeks 2-6) respectively, whereas milk fat and milk protein content declined as expected with time, reaching minimum values in lactation stages 2 and 3 for Trial 1 and stages 3 and 2 for Trial 2 respectively. Daily milk yield steadily increased from calving, reaching peak yield (measured as the highest daily yield) of 36.4 kg at week 6.6 for Trial 1 and 30.3 kg in week 8.9 for Trial 2. Over 2-24 weeks of lactation cows produced daily in Trial 1 28.4 kg milk containing 42.1 fat and 34.7 g/kg protein; 29.4, 1.19 and 0.99 kg FCM, milk fat and milk protein respectively (Table A.9). Milk and FCM yields over 305 days of lactation were 7236 and 7656 kg respectively. Similarly, in Trial 2 the animals over 2-24 weeks of lactation produced 24.7 kg milk containing 42.5 fat and 34.3 g/kg protein; 25.6, 1.05 and 0.85 kg FCM, milk fat and milk protein respectively (Appendix Table A.9). In 305 days of lactation the aniamls of Trial 2 also produced 6621 and 7051 kg respectively of milk and FCM.

There was a small but consistent inverse relationship between milk yield and milk constituents in both trials (Appendix Table A.17). Correlations

Table 4.1 Means, standard deviations (SD), residual standard deviations (RSD) and variance (R^2%) accounted by Model 1 for milk yield traits per stage of lactation - TRIAL 1

TRAIT	Mean	SD	RSD	R^2
Milk yield (kg/day)				
Stage 1	31.5	4.97	3.41	58.9
2	31.6	5.18	4.38	38.0
3	27.1	4.69	4.24	29.7
4	23.6	4.45	4.21	23.3
1-4	28.4	4.27	3.43	43.9
Peak yield (kg/day)	36.4	5.37	4.10	50.0
305-day milk yield (kg)	7236	1230	1129	31.3
Week of peak milk yield	6.6	3.25	2.45	20.3
Persistency of milk yield	4.0	0.53	0.50	23.4
Fat corrected milk (FCM) yield (kg/day)				
Stage 1	33.2	6.10	3.97	63.6
2	31.6	5.52	4.82	34.4
3	27.6	5.00	4.47	31.2
4	24.8	5.03	4.80	23.2
1-4	29.3	4.64	3.74	43.9
Peak FCM yield (kg/day)	38.7	6.62	5.09	49.2
305-day FCM yield (kg)	7656	1460	1382	26.1
Milk fat content (g/kg)				
Stage 1	43.5	7.08	5.78	42.7
2	40.1	5.27	5.07	20.5
3	41.3	4.97	4.73	22.2
4	43.3	5.11	4.89	21.4
1-4	42.1	4.21	4.14	17.0
Milk protein content (g/kg)				
Stage 1	35.0	2.78	2.60	24.5
2	33.8	2.59	2.20	37.8
3	33.7	2.54	2.26	32.3
4	35.3	2.96	2.57	35.2
1-4	34.7	2.33	2.04	36.4

Table 4.2 Means, standard deviations (SD), residual standard deviations (RSD) and variance (R^2%) accounted by Model 2 for milk yield traits per stage of lactation - TRIAL 2

TRAIT	Mean	SD	RSD	R^2
Milk yield (kg/day)				
Stage 1	25.9	5.96	1.85	91.5
2	26.5	4.48	2.48	72.9
3	24.1	3.79	2.76	52.0
4	22.2	3.66	3.18	33.0
1-4	24.7	3.96	2.05	76.5
Peak yield (kg/day)	30.3	5.86	2.23	87.2
305-day milk yield (kg)	6621	978	728	59.1
Week of peak milk yield	8.9	4.34	4.21	19.8
Persistency of milk yield	4.35	0.445	0.326	52.7
Fat corrected milk (FCM) yield (kg/day)				
Stage 1	27.1	6.58	2.69	85.2
2	27.0	4.73	2.91	66.5
3	25.0	4.40	3.43	46.5
4	23.2	4.41	3.86	32.3
1-4	25.6	4.46	2.68	68.2
Peak FCM yield (kg/day)	32.1	6.82	3.32	78.9
305-day FCM yield (kg)	7051	1254	988	48.4
Milk fat content (g/kg)				
Stage 1	43.1	5.36	4.70	32.2
2	41.4	4.26	4.09	18.5
3	42.5	4.39	4.23	17.8
4	43.1	4.68	4.64	13.3
1-4	42.5	3.76	3.63	17.7
Milk protein content (g/kg)				
Stage 1	33.8	2.55	2.28	29.6
2	33.6	2.32	2.08	29.2
3	34.8	2.52	2.32	24.7
4	34.9	3.07	2.57	38.0
1-4	34.3	2.16	1.95	28.2

Table 4.3 Least squares means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily milk yield (kg) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	29.9	0.59	30.4	0.75	26.6	0.72	23.5	0.71	27.8	0.59
Parity											
2	26	28.5	1.01	29.2	1.28	26.5	1.24	24.5	1.24	27.4	1.02
3	34	30.0	0.78	30.3	1.00	26.1	0.96	22.9	0.95	27.7	0.79
4	25	29.9	0.83	30.4	1.06	26.0	1.03	22.4	1.02	27.4	0.83
5	30	31.0	0.82	31.8	1.06	27.7	1.02	24.3	1.02	28.7	0.83
R^2		2.6		3.1		2.8		2.6		2.9	
Condition score groups											
1	65	30.2	0.68	30.3	0.89	25.9	0.84	22.6	0.84	27.4	0.69
2	26	30.6	0.76	30.9	0.97	26.2	0.93	22.8	0.93	28.0	0.77
3	24	28.8	1.44	30.0	1.85	27.7	1.78	25.2	1.76	28.1	1.44
R^2		3.0		3.4		4.5		4.3		3.3	
Weight change (b,SE)	115	-0.0380	0.0604	-0.2152	0.1249	-0.1277	0.0137	-0.0368	0.1314	-0.5838	0.1814**
R^2		0.2		1.2		0.8		0.4		4.9	
Calving liveweight (b, SE)	115	-0.00041	0.00812	0.00130	0.01011	0.00692	0.00972	0.01069	0.00960	-0.00047	0.00805
R^2		0.2		0.3		0.1		0.1		0.1	

abcd Different superscripts in column indicate significant difference $P < 0.05$, ** $P < 0.01$

Table 4.4 Least squares means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily fat corrected milk (FCM, kg) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	31.9	0.68	30.6	0.82	27.1	0.76	24.6	0.82	28.8	0.64
Parity											
2	26	30.3	1.16	30.7	1.41	27.7	1.32	26.2	1.42	29.1	1.00
3	34	33.1	0.90	31.2	1.10	27.1	1.01	24.3	1.08	29.3	0.86
4	25	31.8	0.96	29.4	1.16	26.3	1.08	23.0	1.16	27.9	0.90
5	30	32.4	0.95	31.3	1.16	27.4	1.07	24.8	1.15	29.0	0.90
R^2		2.1		1.2		0.7		2.4		1.0	
Condition score groups											
1	65	32.2	0.79	30.8	0.97	26.8	0.89	24.3	0.96	28.8	0.75
2	26	31.6	0.88	30.6	1.07	26.2	0.98	23.8	1.06	28.5	0.83
3	24	31.9	1.66	30.5	2.03	28.4	1.88	25.6	2.01	29.2	1.56
R^2		3.2		3.6		4.8		4.2		3.9	
Weight change (b,SE)	115	-0.2057	0.0971**	-0.2322	0.1371	-0.1674	0.1429	-0.0957	0.1502	-0.6860	0.1965**
R^2		2.8		2.0		1.1		2.4		5.8	
Calving liveweight (b,SE)	115	0.00527	0.00930	0.01323	0.01100	0.01104	0.01032	0.01372	0.01101	0.00544	0.00871
R^2		0.1		0.3		0.4		0.4		0.2	

abcd Different superscripts in column indicate significant difference $P < 0.05$, ** $P < 0.01$

Table 4.5 Least squares means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) for milk fat content (g/kg) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	44.7	0.98	40.6	0.86	41.4	0.80	42.9	0.83	42.2	0.71
Parity											
2	26	43.6	1.67	40.9^{a}	1.46	43.0^{a}	1.37	44.3^{a}	1.42	43.3^{a}	1.29
3	34	47.0	1.31	42.0^{a}	1.16	42.6^{a}	1.07	44.2^{a}	1.06	43.8^{a}	0.95
4	25	44.5	1.38	38.4^{b}	1.21	40.9^{b}	1.13	42.0^{b}	1.17	41.3^{b}	0.99
5	30	43.7	1.33	39.1^{b}	1.17	39.0^{c}	1.09	41.1^{b}	1.12	40.5^{b}	0.91
Condition score groups											
1	65	43.4	1.08	40.7	0.94	42.1	0.86	44.8	0.89	43.0	0.76
2	26	42.4	0.95	39.3	1.14	40.3	1.06	42.6	1.09	41.1	0.93
3	24	44.0	1.05	41.7	2.07	41.7	1.93	41.2	1.99	42.7	0.17
Weight change (b,SE)	115	-0.3728	0.1004**	-0.0183	0.1442	-0.0957	0.1507	-0.1772	0.1521	-0.0203	0.0216
Calving liveweight (b,SE)	115	0.00272	0.00879	0.01641	0.00759*	0.00825	0.00708	0.00503	0.00731	0.00091	0.00063

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 4.6 Least squares means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) for milk protein content (g/kg) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	Number of records	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
All	115	34.5	0.44	33.5	0.37	34.8	0.38	35.4	0.44	34.5	0.34
Parity											
2	26	33.6	0.76	32.9	0.64	34.7	0.66	35.5	0.76	33.9	0.59
3	34	34.8	0.59	33.6	0.50	35.2	0.51	35.7	0.58	34.6	0.46
4	25	35.0	0.63	34.0	0.53	35.1	0.54	35.6	0.62	34.9	0.48
5	30	34.8	0.62	33.6	0.53	34.4	0.54	34.6	0.62	34.4	0.48
Condition score groups											
1	65	35.9	0.51	34.3	0.44	35.6	0.45	35.9	0.51	35.3	0.40
2	26	34.6	0.57	33.8	0.49	34.8	0.49	35.4	0.57	34.5	0.44
3	24	33.1	1.09	32.4	0.93	34.1	0.94	34.8	1.08	33.5	0.83
Weight change (b,SE)	115	0.1582	0.0455**	0.2677	0.0626**	0.1247	0.0717	0.0076	0.0801	0.4411	0.1052**
Calving liveweight (b,SE)	115	0.00256	0.00612	0.00613	0.00501	0.00150	0.00510	0.00475	0.00594	0.00134	0.00461

abcd Different superscripts in column indicate significant difference $P < 0.05$, ** $P < 0.01$

Table 4.7 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily milk yield (kg) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.2233	0.0668**	-0.3977	0.1330**	-0.3297	0.1576**	-0.2936	0.2212	-0.8484	0.1925**
R^2		2.4		3.4		3.1		1.3		7.1	
Calving liveweight (b,SE)	75	-0.00051	0.06190	-0.00488	0.00820	0.00470	0.00889	0.01018	0.01045	-0.00278	0.00678
R^2		0.1		0.1		0.1		0.3		0.1	
Calving condition score (b,SE)	75	-0.7771	1.074	-0.0282	1.461	-1.607	1.610	-3.093	1.853	-1.161	1.194
R^2		0.1		0.1		0.5		3.0		0.6	
Parity groups											
1a	24	21.3^a	0.69	22.9^a	0.60	21.7^a	0.66	20.5^a	0.70	21.6^a	0.59
1b	25	23.4^b	0.67	25.5^b	0.59	24.4^b	0.65	23.2^b	0.69	24.1^b	0.58
2	14	32.0^c	0.92	29.3^c	0.80	25.5^b	0.88	22.7^b	0.90	27.3^c	0.78
3	12	33.1^d	0.95	32.2^d	0.83	26.8^b	0.92	23.0^b	0.98	28.9^d	0.81
All	75	25.9	0.41	26.5	0.36	24.1	0.39	22.2		24.7	0.34
Level of significance		***		***		***		**		***	

^{abcd} Different superscripts in column indicate significant difference $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$

Table 4.8 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily fat corrected milk (FCM, kg) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.3983	0.0974**	-0.4715	0.1560**	-0.3676	0.1959	-0.1667	0.2688	-0.9918	0.2507**
R^2		3.7		4.3		2.8		0.4		7.3	
Calving liveweight (b,SE)	75	0.00930	0.00903	-0.00495	0.00962	0.00952	0.01106	0.00884	0.01127	0.00041	0.00884
R^2		0.2		0.0		0.2		0.0		0.0	
Calving condition score (b,SE)	75	-1.326	1.566	-0.4971	1.714	-3.283	2.002	-3.987	2.250	-2.129	1.555
R^2		0.2		0.2		1.7		3.0		1.0	
Parity groups											
1a	24	21.8^a	0.84	22.8^a	0.66	22.0^a	0.78	21.1^a	0.85	22.0^a	0.69
1b	25	25.1^b	0.82	26.8^b	0.65	25.9^b	0.76	24.6^b	0.82	25.7^b	0.67
2	14	34.3^c	1.12	29.9^c	0.89	26.1^b	1.04	23.0^c	1.12	28.2^c	0.92
3	12	33.4^c	1.16	32.2^d	0.92	27.9^c	1.07	24.8^b	1.17	29.8^d	0.96
All	75	27.1	0.50	27.0	0.39	25.0	0.46	23.2	0.50	25.6	0.41
Level of significance		***		***		***		**		***	

^{abcd} Different superscripts in column indicate significant difference $P < 0.05$

*** = $P < 0.001$ ** = $P < 0.01$ * = $P < 0.05$

Table 4.9 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score and liveweight change - kg/week (regression coeffieints (b)) for milk fat content (g/kg) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.3408	0.1686*	-0.1072	0.2202	-0.0589	0.2420	0.3065	0.3230	-0.2408	0.3398
Calving liveweight (b,SE)	75	0.0224	0.0150	-0.00141	0.00132	0.00747	0.01318	-0.00897	0.01472	0.00429	0.01153
Calving condition score (b,SE)	75	-0.1908	0.1523	-0.1431	0.1227	-0.0881	0.1251	0.0733	0.1361	-0.0771	0.1121
Parity groups											
1a	24	41.6[a]	1.03	39.8	0.80	41.0[a]	0.85	42.3	0.92	41.1[a]	0.72
1b	25	44.9[b]	1.01	43.6	0.78	44.4[b]	0.83	44.2	0.91	44.4[b]	0.71
2	14	44.4[b]	1.38	41.5	1.06	41.7[a]	1.13	41.3	1.23	42.2[c]	0.96
3	12	40.8[a]	1.43	40.1	1.11	42.4[c]	1.17	44.3	1.28	41.9[a]	0.99
All	75	43.1	0.61	41.4	0.48	42.5	0.50	43.1	0.55	42.5	0.43
Level of significance		*		**		*		NS		*	

[abcd] Different superscripts in column indicate significant difference $P < 0.05$

** = $P < 0.01$ * = $P < 0.05$ NS = not significant

Table 4.10 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score and liveweight change - kg/week (regression coefficients (b)) for milk protein content (g/kg) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.0231	0.0818	0.0108	0.1118	0.2467	0.1328	0.3621	0.1790*	0.1032	0.1828
Calving liveweight (b,SE)	75	0.00704	0.00728	-0.00014	0.00665	0.00027	0.00723	0.00091	0.00816	0.00312	0.00620
Calving condition score (b,SE)	75	-0.2191	0.0739	-0.0856	0.0623	-0.0694	0.0684	0.0241	0.0754	-0.0670	0.0599
Parity groups											
1a	24	34.3^{a}	0.49	33.7	0.45	34.0^{a}	0.47	34.5^{a}	0.52	34.3^{a}	0.38
1b	25	33.1^{b}	0.48	33.2	0.44	34.3^{ab}	0.46	34.1^{ab}	0.51	33.7^{b}	0.39
2	14	33.0^{b}	0.65	33.1	0.61	33.7^{b}	0.62	33.7^{b}	0.70	33.4^{b}	0.52
3	12	35.3^{c}	0.68	35.1	0.63	37.0^{c}	0.65	38.6^{c}	0.72	36.5^{c}	0.54
All	75	33.8	0.29	33.6	0.26	34.8	0.28	34.9	0.31	34.3	0.23
Level of significance		*		NS		*		**		**	

abcd Different superscripts in column indicate significant difference $P < 0.05$

** = $P < 0.01$ * = $P < 0.05$ NS = not significant

between yields of daily milk and FCM in different stages of lactation declined as the time between stages increased (Appendix Table A.16). Within cow correlations between milk yield in the same stage of lactation in consecutive lactations were small (Appendix Table A.17 and Appendix Figure A.3); those between 305-day milk or FCM yields were moderate (r = 0.42-0.58).

4.1.2 EFFECTS OF DIFFERENT FACTORS ON MILK PRODUCTION

The effects of different factors on average daily and 305-day milk and FCM yields and milk fat and milk protein contents were tested by analysis of variance.

Model 1 (which included year of calving, month of calving, parity, daily milk yield (MY) in lactation week 2, calving condition score (CS), MY x CS, weekly liveweight change in the stage of lactation and calving liveweight) explained 23.3 and 63.6% of the variation, in various lactation stages, for these traits in Trial 1 (Table 4.1). Similarly, Model 2 which included all these factors except year of calving and MY x CS accounted for 33.0 and 91.5 of the variation in these same traits in Trial 2 (Table 4.2). The corresponding least squares means of these traits for Trial 1 are provided in Tables 4.3-4.6 and Appendix Tables A.10-A.14. For Trial 2 the unadjusted parity group means and least squares means of these same traits are given in Tables 4.7-4.10 and Appendix Tables A.18-A.22.

Year of calving was not an important source of variation in daily milk yield accounting for only 0.3-2.0% of the variation in this trait (Appendix Table A.10). All years, however, differed from each other in milk protein content with year 2 animals producing the highest protein

content in milk.

Also, for Trial 1, month of calving had no significant consistent influence on milk yields and milk composition, although September calvers tended to produce the highest yields of milk and milk constituents. In Trial 2, on the other hand, month of calving significantly influenced ($P < 0.05$) milk fat content (lactation stage 1) and milk protein content (lactations stages 1 and 2). Differences in milk fat content was caused by October calvers producing higher fat content milk whereas differences in milk protein could not consistently be attributed to a single month of calving (Appendix Tables A.21 and A.22).

Parity in Trial 1, after adjustment of the data, was surprisingly not an important source of variation in milk production traits except milk fat content. Parity 2 and 3 animals tended to produce a higher milk fat content in all lactation stages after stage 1 (Table 4.5).

However, as would be expected for results of Trial 2 (cows and heifers), cows significantly ($P < 0.01$) produced more unadjusted daily yields of milk than heifers. Cows subsequent to parity 2 also produced significantly ($P < 0.05$) higher protein content in the milk. It is, however, interesting to note that year 5 heifers produced significantly ($P < 0.05$) more milk fat content in most lactation stages (Table 4.9). Furthermore, these same heifers produced ($P < 0.05$) 818 and 1357 kg (unadjusted means) and 376 and 877 kg (adjusted means) more 305-day milk and FCM yields respectively than year 4 heifers (Appendix Table A.18). Also, as would be expected, second parity cows produced less milk than mature cows. The noticeable aspect of the present results was, however, similar milk and FCM yields produced by heifers (year 5) and cows in 305 days

of lactation even though heifers produced lower daily milk yields during the experimental period; indicating not only genetic improvement but also high persistency of milk yield in this group of heifers.

Differences between parity groups in unadjusted milk yields and composition data during the experiment are respectively illustrated in Figures 4.1-4.4. Heifers, as anticipated, had lower daily milk yields, were more persistent and reached peak milk yields later than cows; differences between the 2 groups declined as lactation progressed. Thus differences between the same cow as a hefer (year 4) and as a 2nd calver (year 5) in daily milk and FCM yields were respectively 10.8 and 12.5 kg in lactation stage 1 but 2.2 and 1.9 kg by lactation stage 4. Regression coefficients indicate that this daily difference was 47.5% in lactation weeks 2-6 but only 5.2% in lactation weeks 19-24 (Appendix Table A.17). Furthermore, over 305 days, this average difference between the same animals as a heifer and 2nd calver was 984 and 1108 kg for milk and FCM yields respectively.

Consistent with expectations, daily milk yield in lactation week 2 was well correlated to daily and 305-day milk and FCM yields in both trials. It accounted for 15.3-34.4 and 14.5-20.1% of the variation in daily milk and FCM yields respectively for Trial 1 (Appendix Tables A.10 and A.11). This factor explained less variation in these same traits for Trial 2 (Appendix Tables A.19 and A.20).

Average daily milk and FCM yields over the whole lactation increased with increasing daily milk yields in lactation week 2, but at a declining rate as lactation progressed. This is well illustrated in Figures 4.5 and 4.6 where differences between milk yield groups (see Chapter 2.8 for

groupings) in unadjusted daily milk and FCM yields declined with advancing lactation due to earlier peaking and lower persistency in milk yields for high yielders (MY_3) compared to low yields (MY_1). Also for Trial 2 the regression coefficients of daily milk and FCM yields on daily milk yield in lactation week 2 declined from 0.6-0.4 kg and 0.5-0.4 kg respectively (from lactation stage 1 to stage 4).

One other interesting aspect of the present results was the lack of significant relationship between milk yield in lactation week 2 with subsequent milk composition in both trials except milk protein in lactation stage 1 for Trial 2 (Figure 4.8 and Appendix Tables A.13 and A.22).

Calving condition score proved surprisingly not to be an important factor influencing milk yields and milk composition for Trial 1. There was, however, a tendency for milk protein content to decline ($P < 0.08$) with increasing calving condition score in lactation stage 1 (Table 4.6). The influence of calving condition score on unadjusted daily milk and FCM yields and milk fat and milk protein contents are shown in Figures 4.9-4.12 respectively. CS3 animals (fat) produced more daily milk and FCM yields and milk fat content (lactation weeks 2-10) but appreciably less protein content. It is interesting to note the consistent crossovers in lactation week 10; at this stage CS2 and CS3 animals continued to decline in milk fat content whereas CS1 animals continued to increase in milk fat content (Figure 4.11). The unadjusted means should, however, be viewed with caution due to confounding effects of other factors, such as milk production level, on these traits.

Similarly, for Trial 2 calving condition score had no significant effect

on daily and 305-day milk and FCM yields. This factor was surprisingly inversely related to these traits. Thus a unit increase in calving condition score depressed 305-day milk and FCM yields by 739.3 and 920.4 kg respectively (Appendix Table A.18). There was, however, a significant interaction ($P < 0.05$) between calving condition score and parity groups on milk fat content (lactation stage 3) and milk protein content (lactation stage 1). The regression coefficients of milk fat and milk protein contents on calving condition score for individual parity groups were ($b \pm SE$)

Milk Fat Content
(lactation stage 3)

0.783 ± 4.665; 3.363 ± 4.331; $-5.723^{*} \pm 2.507$; $-14.173^{**} \pm 5.050$ g/kg per unit condition

Milk Protein Content
(lactation stage 1)

2.488 ± 2.700; 1.238 ± 2.421; $-4.552^{**} \pm 1.601$; $-2.584^{**} \pm 0.857$ g/kg per unit condition score for years 4 (1a) and 5 (1b) heifers, parity 2 and older cows respectively.

Where ** = $P < 0.01$ and * = $P < 0.05$

It is interesting to note the significant decline in both milk fat and milk protein with increasing CS for cows but not heifers.

Weekly weight change as anticipated was correlated with milk production traits for both trials. It had a significant inverse relationship ($P < 0.05$) with daily and 305-day milk yields and milk fat content in various stages of lactation for both trials (Tables 4.3-4.5 and 4.7-4.9 and Appendix Tables A.14-A.18). Milk protein content, on the other hand, increased ($P < 0.05$) with increasing weekly weight change (Tables 4.6 and 4.10).

Milk yields were more depressed, by increasing weekly weight change, in Trial 2 than Trial 1. Thus daily milk and FCM yields respectively declined by 0.6 and 0.2-0.7 kg (for Trial 1), but 0.2-0.8 and 0.2-1.0 kg (for Trial 2) for 1 kg increase in weekly weight change. Also a 1 kg increase in weekly weight change in lactation weeks 2-6 was associated with lower 305-day milk and FCM yields respectively by 147.5 and 161.8 kg for Trial 1, but 247.6 and 247.3 kg for Trial 2.

The results of Trial 2 further indicate that the relationships between weekly weight change and daily FCM yield (lactation stage 2) and milk fat content (lactation stage 1) were influenced by parity groups. The slopes of the individual parity group regression of daily FCM yield and milk fat content on weekly weight change were (b $\pm$ SE):

FCM Yield
(lactation stage 2)

-0.0488 ± 0.2112; $-0.2929^{*} \pm 0.1658$; $-0.7676^{**} \pm 0.2856$; -0.2338 ± 0.1479 kg/kg weekly weight change

Milk Fat Content
(lactation stage 1)

0.2834 ± 0.3892; $-0.7839^{*} \pm 0.299$; -0.4211 ± 0.5430; -0.1859 ± 0.2674 g/kg per kg weekly weight change for heifers of years 4 (1a) and 5 (1b), parity 2 and older cows respectively.

Where ** = $P < 0.01$ and * = $P < 0.05$

The striking aspect of these regression coefficients is the significant decline in FCM and milk fat content with increasing weight change for year 5 heifers, indicating a marked ability to partition more of their food into milk fat than gain.

Of the factors examined, calving liveweight proved the least important

Figure 4.1 : Mean milk yields(kg/day) between weeks 2 and 24 of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.),Second calvers(O),YR4 Heifers(X),YR5 Heifers(x).

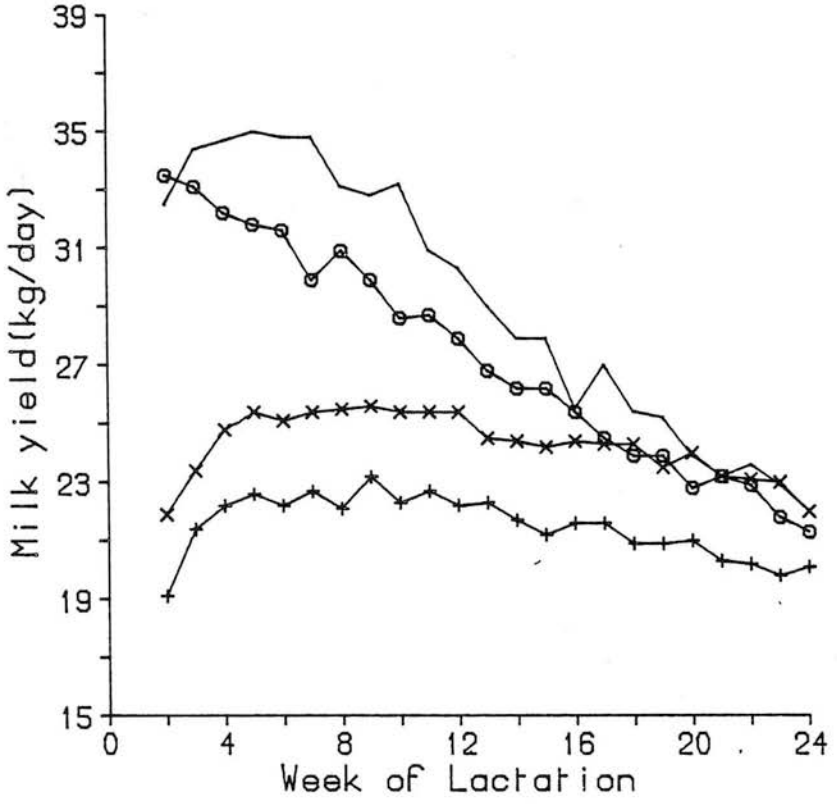


Figure 4.2 : Mean FCM yields(kg/day) between weeks 2 and 24 of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.),Second calvers(O),YR4 Heifers(+),YR5 Heifers(x).

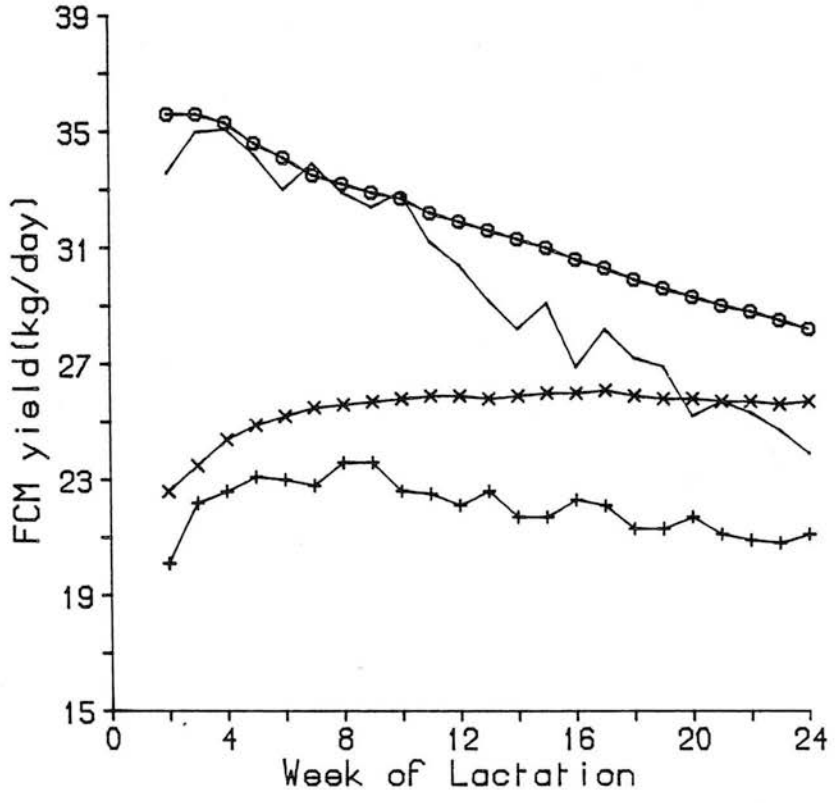


Figure 4.3 : Mean milk fat contents(g/kg) between weeks 2 and 24 of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.),Second calvers(o),YR4 Heifers(+),YR5 Heifers(x).

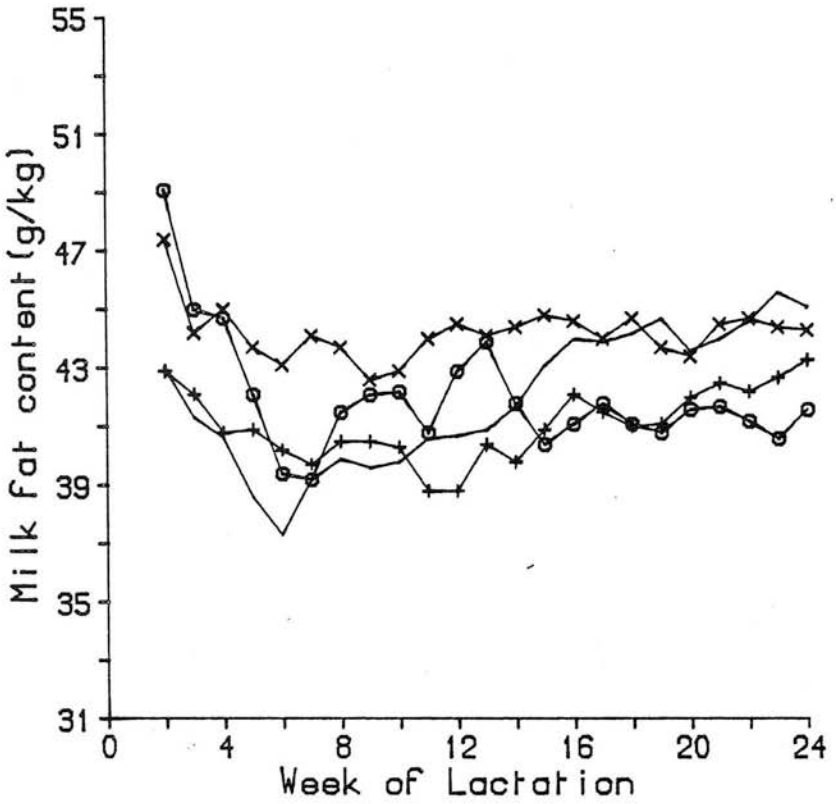


Figure 4.4 : Mean milk protein contents(g/kg) between weeks 2 and 24 of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.),Second calvers(o),YR4 Heifers(+),YR5 Heifers(x).

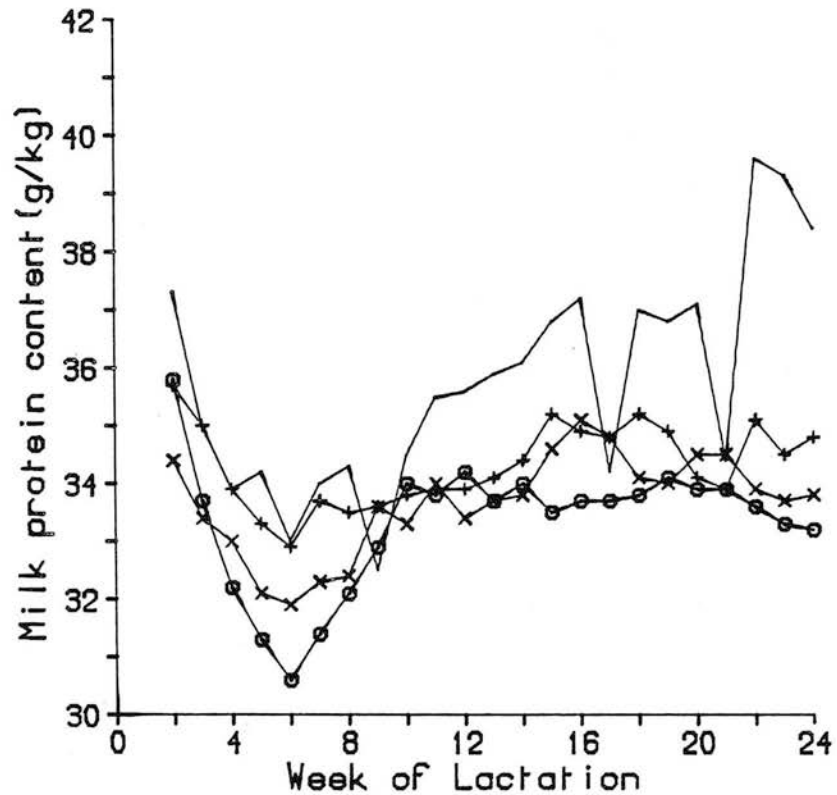


Figure 4.5 : Mean milk yields(kg/day) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

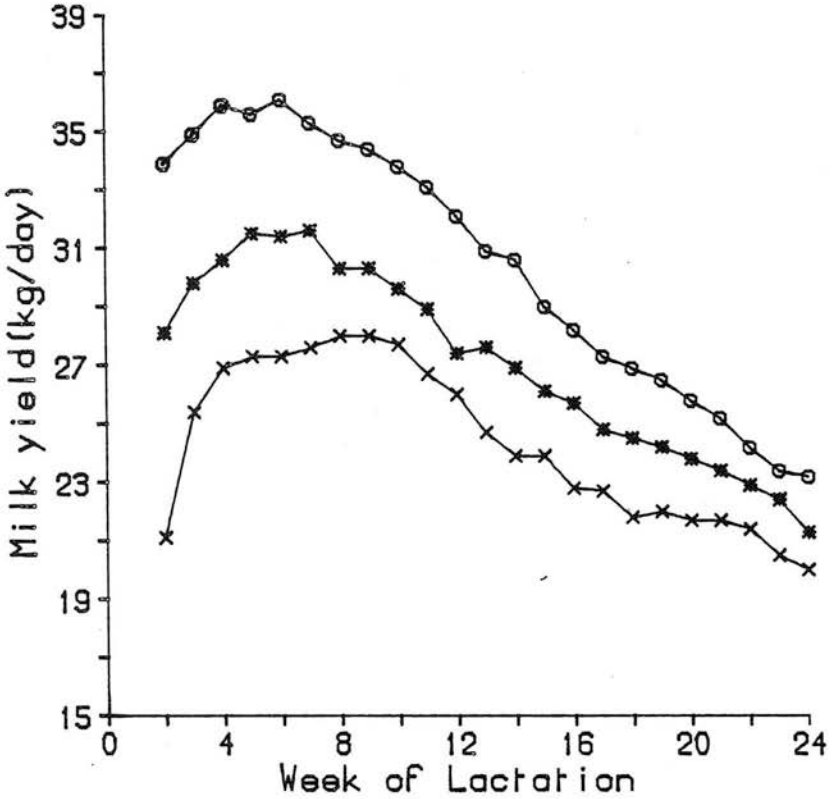


Figure 4.6 : Mean FCM yields(kg/day) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

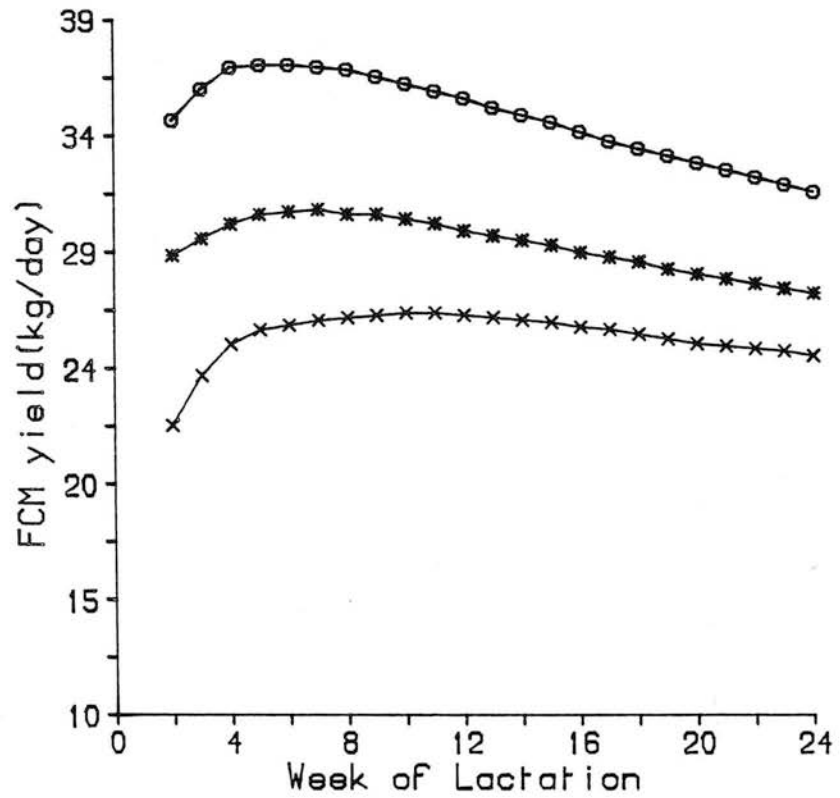


Figure 4.7 : Mean milk fat contents(g/kg) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

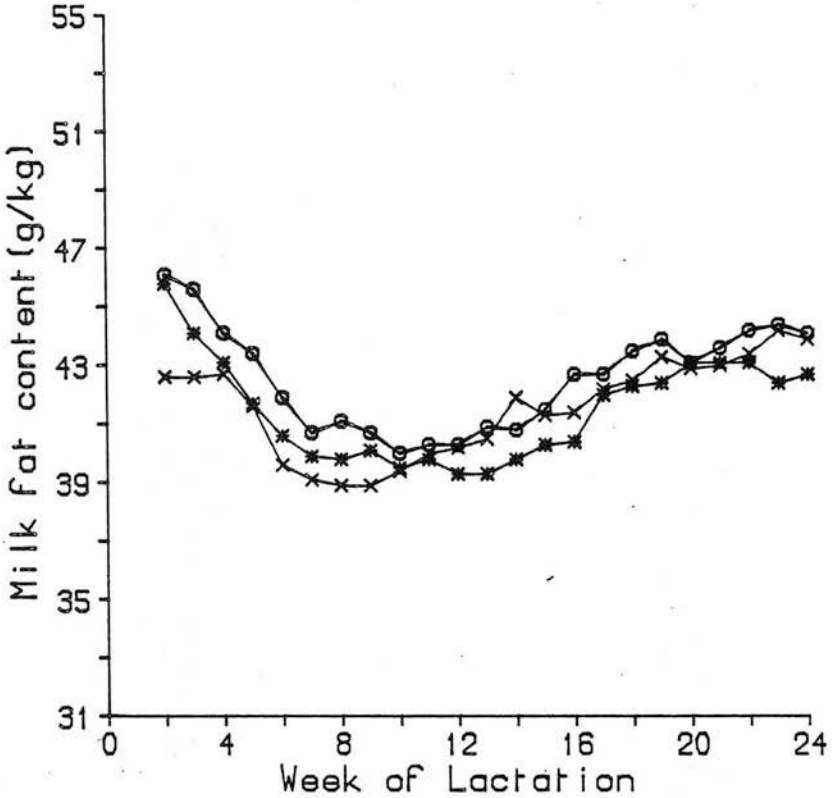


Figure 4.8 : Mean milk protein contents(g/kg) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

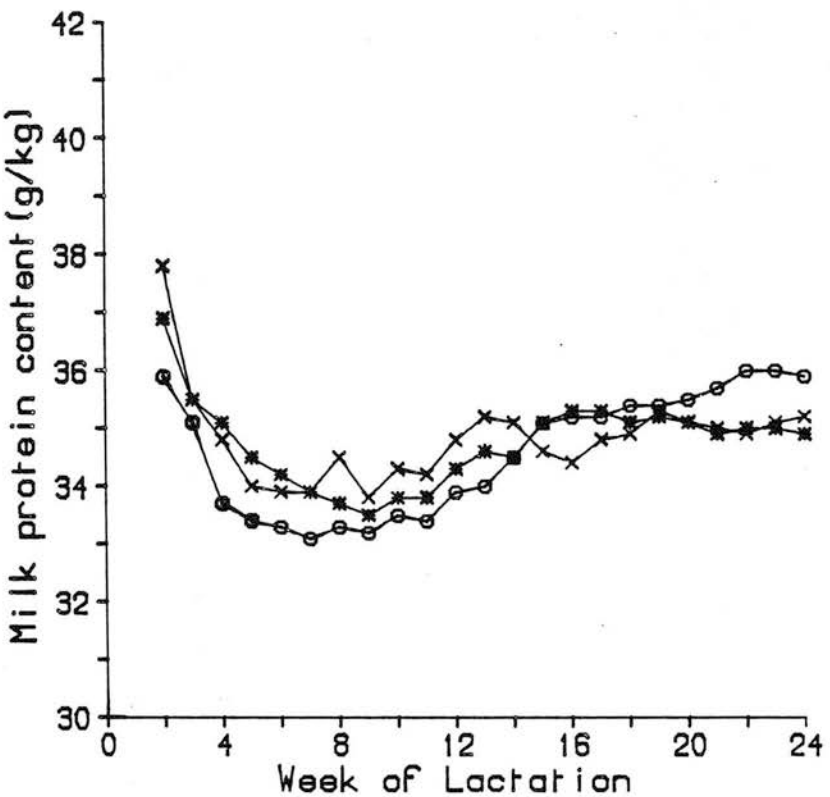


Figure 4.9 : Mean milk yields(kg/day) between weeks 2 and 24 of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).

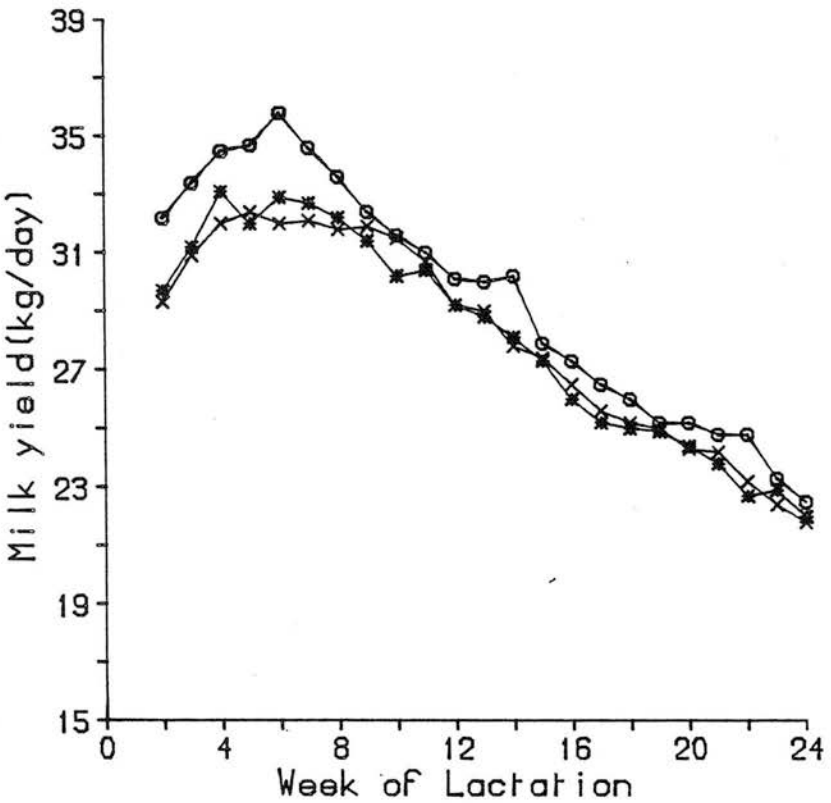


Figure 4.10 : Mean FCM yields(kg/day) between weeks 2 and 24 of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).

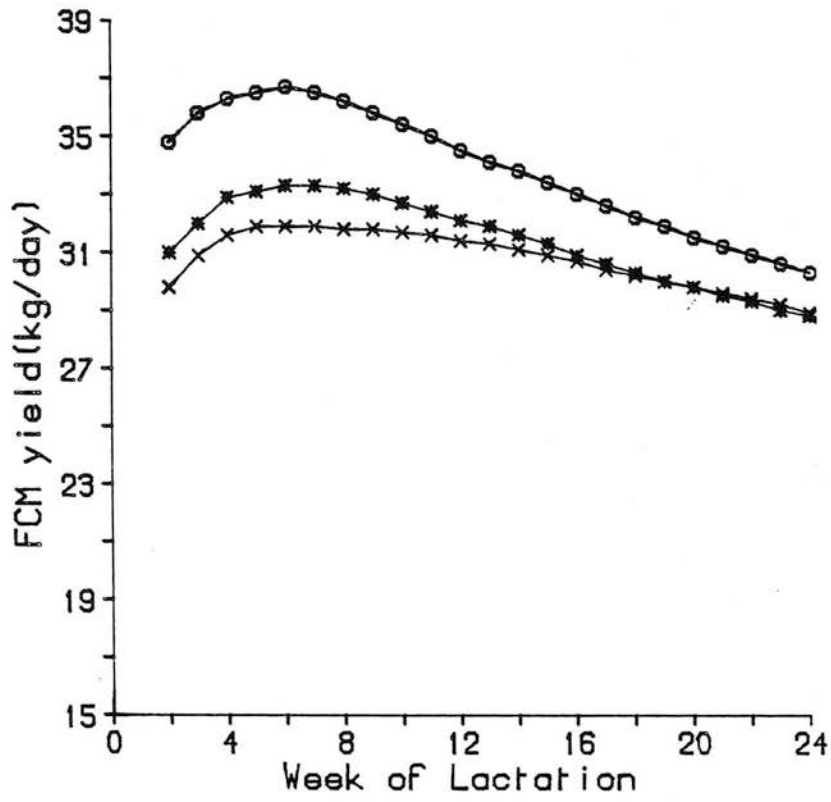


Figure 4.11 : Mean milk fat contents(g/kg) between weeks 2 and 24 of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).

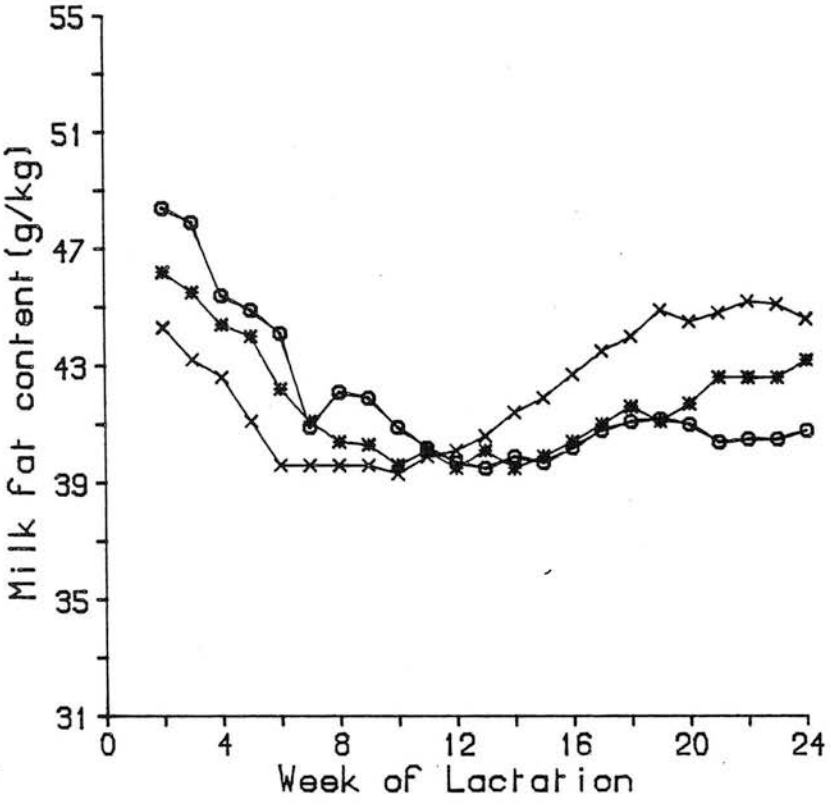
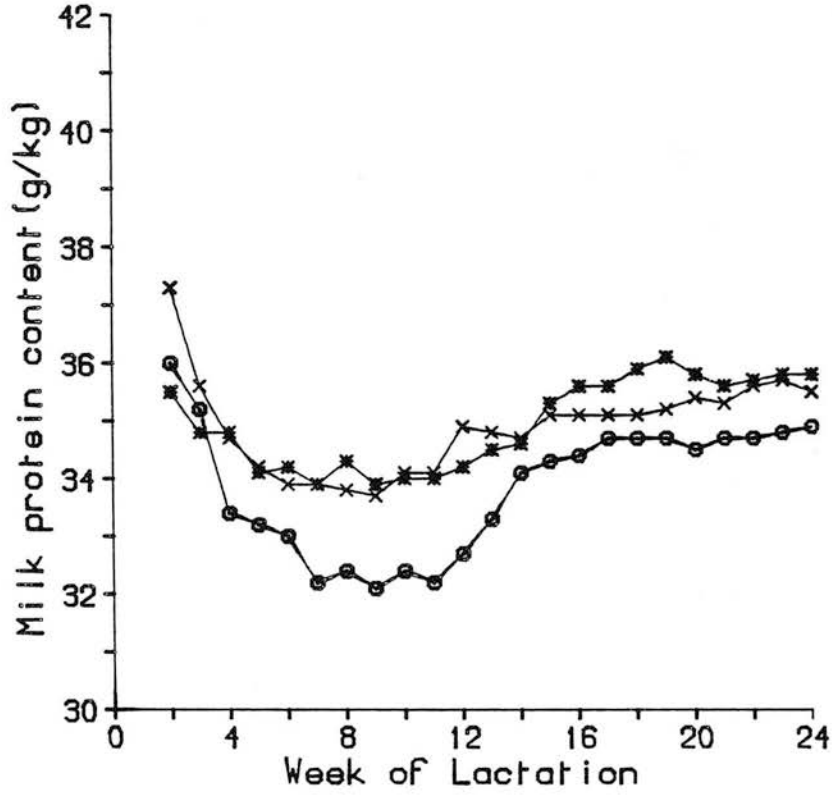


Figure 4.12 : Mean milk protein contents(g/kg) between weeks 2 and 24 of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).



factor influencing milk yields and milk composition for both trials; although it inconsistently had a significant positive ($P < 0.05$) effect on milk fat content in lactation stage 2 for Trial 1 (Table 4.5).

4.2 Discussion

4.2.1 GENERAL

Variations in milk yield between cows can be influenced both by environmental and animal factors. Variations in level of feeding is one of the most important factors causing differences between herds or between animals in milk yield (Wiktorrson, 1980). Previous level of feeding of the cow may also be important (see reviews Broster, 1971; Broster and Broster, 1984). It is therefore important to separate these different sources of variation in order to arrive at an estimate of their relative importance. This was attempted in the present analysis. The factors studied here were year and month of calving (environmental factors), daily milk yield in lactation week 2, calving liveweight and condition score, parity and average weekly weight change in the stage of lactation (animal factors).

Also the animals in this study were managed to allow each animal to express its genetic potential for milk production based on its ability to have high voluntary intakes of high energy mixed diets presumed to be adequate in crude protein and all other nutrients and offered ad libitum. In the dry period they were allowed to replenish body reserves lost in the previous lactation. Based on this system of management the cows on average produced 7,236 kg and the heifers 6,406 kg milk in 305 days of lactation. By the definition of Broster and Alderman (1977) these

animals could be classified as high yielding in the UK.

The pattern of milk yields of the cows follow the normal pattern of a rapid rise from calving to peak in weeks 7-9 of lactation (Tables 4.1 and 4.2). Normally cows reach peak yields of milk in weeks 5-7 (Broster et al, 1982). Wood (1980a), however, noted that cows producing over 10,000 kg in 305 days of lactation peaked later than this norm (8.5 vs 5.0 weeks).

Between cow variation in milk yield was lowest in early lactation and highest later in lactation (coefficient of variation (CV%) = 15.8 vs 18.9). However, when cows and heifers are considered together (Trial 2) the reverse was the case (CV% = 23.0 vs 16.5). Milk yield also varied less than FCM yield (15.8-23.0 vs 18.4-24.3% lactation weeks 2-6 and 16.5-18.9 vs 19.0-20.3% in weeks 19-24). These values are not surprising since FCM yields will depend a lot more on variation in milk fat content caused by variation in the mobilization of body fat than actual milk yield. Low milk yields, in early lactation, but high persistency of heifers compared to cows (Broster and Broster, 1984) were probably responsible for the pattern of between animal variation for milk yields observed in Trial 2.

The average coefficient of variation of 16% observed in 305-day milk yield was smaller than the 25% reported by Broster et al (1969). The results in the present investigation indicate the relative uniformity of the heifers resulting in only 17% CV when compared with cows.

Milk fat and milk protein contents had converse patterns to milk yield (Oldham and Sutton, 1979) resulting in small but consistent negative correlations between these traits. Milk fat and protein contents were

high in early lactation but declined to minimum levels in lactation weeks 7-12 then increased. Milk composition was also less variable than milk yield. This change in pattern of milk composition has been noted by many other workers. Crabtree (1984) in a review of the literature on milk compositional ranges and trends showed that milk fat content reached a minimum in weeks 6-10 of lactation while milk protein content reached a minimum in lactation week 6. It is suggested that the inverse relationship between milk yield and milk fat content is due to competition for available energy by the 2 variables (Brown et al, 1981). Perhaps a similar effect is involved in the relationship between milk protein content and milk yield; increased ME intake from carbohydrate sources increased milk protein content (Thomas, 1984). The supply of high energy diets in the present investigation was probably responsible for the low negative correlations between milk yield and milk composition.

The animals in the current study also produced milk higher in quality than values reported for the UK (Crabtree, 1984). This was 42.0-42.5 vs 37.8 g/kg for milk fat content and 34.3-34.7 vs 32.6 g/kg for milk protein content (produced by British Friesians). These large differences are to be expected as the cows in the present experiment were selected for high milk constituents.

The analysis of variance models indicate that it is more accurate to predict daily milk and FCM yields than milk composition from environmental and animal factors. This could be due to the low CV in milk composition compared to milk yield (CV = 6.3-10.0 vs 15.0-16.0% over the experimental period). It could also be that under ad libitum feeding animal characteristics have only a small influence on milk

composition, due to higher energy intakes.

It is also more accurate, using these same factors, to predict milk yields of heifers and cows than only cows, probably due to the larger animal variation or greater influence of several animal characteristics in the former case. In Trial 1, for example, Model 1 explained 23.3-58.9% and in Trial 2 Model 2 explained 33.0-91.5% of the total variation in milk yield. Thus daily milk yield of cows alone can be predicted, with Model 1, to within 3.4-4.4 kg while those for cows and heifers, with Model 2, to within 1.8-3.2 kg over 2-24 weeks of lactation. The values are even larger in 305-day milk yields (1129 vs 728 kg). The influence of these factors generally declined with advancing lactation. This suggests that because milk yield is influenced by many factors, previously mentioned, and many of these are independent and tend to be variable during lactation, using animal characteristics early in lactation to predict milk yield later in lactation would be imprecise. This is further evidenced by the moderate correlation coefficients between milk yields in different stages of lactation, separated by several weeks (Appendix Table A.16), or milk yields in consecutive lactations of the same cow (r = 0.42-0.58).

4.2.2 EFFECTS OF DIFFERENT FACTORS ON MILK PRODUCTION

4.2.2.1 Environmental Effects

Year effects on average daily and 305-day milk and FCM yields were small (Appendix Tables A.10, A.11 and A.14). Year effects tended to be more important in milk protein content (Appendix Tables A.12 and A.13). Differences were caused by cows especially of year 2 and 4 producing milk high in protein content. These year differences were

presumably due to the low DMI and therefore low energy and nitrogen intake of animals of years 1 and 3 in early lactation (see Chapter 3.1.2). There is evidence that the yield and content of milk protein varies with the dietary supply of metabolizable energy and protein (Thomas, 1984).

Similarly, month of calving tended to have a significant influence on milk composition rather than on milk yields. In Trial 1 September calvers tended slightly to produce milk lower in fat (in lactation stage 1) but higher in protein content than other monthly groups especially ($P < 0.05$) in lactation stages 3 and 4 (Appendix Tables A.12 and A.13). However, in Trial 2 September calvers produced significantly less milk fat content (lactation stage 1) and milk protein content (lactation stages 1 and 2) than other monthly groups (Appendix Tables A.21 and A.22).

Generally, cows calving in different months of the year differ in milk in a 305-day lactation with summer calving cows generally producing less milk than average (Wood, 1980b). These changes are associated with cyclic changes in daylength, nutrition or management. The lack of monthly difference in the current study could be due to the provision of adequate nutrition. Also the inclusion of liveweight change in the analysis model might have removed some monthly differences.

The low fat content of milk produced by September calvers (lactation stage 1) was probably due to the high concentrate to forage diet fed to these animals. The effect of concentrate:forage ratio on milk fat conent is discussed in detail by Oldham and Sutton (1979) and Sutton (1984). The high protein content in milk for these same animals (Trial 1) in lactation stages 3 and 4 was possibly due to the higher DMI of these cows at this time (Thomas, 1984). For Trial 2, the low milk protein content of

September calvers are difficult to interpret since DMI was similar between months of calving.

4.2.2.2 Effect of Parity

Milk yield over 305 days of lactation is noted to increase from parity 1 to 4 with 1st calvers producing 75-78%, 2nd calvers 85-90% and 3rd calvers 95-98% of the 305-day milk yields of 4th calvers (Schmidt and Van Vleck, 1974; Wood, 1980b). This increase in milk yield with age is attributable to increase in body development, especially of the mammary glands.

Contrary to these observations, parity had no significant influence on milk yield in Trial 1 of the present investigation. This could be due to the adjustments of the present results for environmental and animal factors. For example, in Trial 2 milk yields increased with increasing parity for unadjusted means, but was the converse in the adjusted means (Appendix Table A.18). There are several reasons for this anomaly after adjustments:

(1) Heifers of each generation are improving in milk yield potential and catching up with older cows of the previous generation.

(2) There is no linear relationship between calving liveweight, calving condition score, daily milk yield in lactation week 2 and weekly weight change and milk yields, so adjusting milk yields to the same averages for these variables would benefit immature animals.

Differences between heifers and cows in unadjusted milk yields were usually high in early lactation but differences decreased as lactation progressed (Tables 4.7 and 4.8). These differences were probably due

to high persistency and longer period from calving to peak milk yield observed for heifers than cows already mentioned. This is possibly a reflection of the longer period required for the metabolic system to adjust to the synthesis of milk forming constituents in early lactation for heifers, whereas milk yield differences could be due to differences in mammary secretory tissue development and therefore secretory capacity (Oldham, 1984).

These results are consistent with reports in the literature. Ostergaard (1979) observed that cows produced significantly more milk than heifers and that these differences narrowed as lactation progressed. Oldenbroek (1984b) observed that differences in 305-day milk yield between 2nd parity and 1st parity cows was 771, 561 and 635 kg for Holstein-Friesians, Dutch Red and White cattle and Dutch Friesian cattle, respectively. In this work differences ranged from 136 (heifers year 5) to 537 kg (heifers year 4). It is interesting to note, however, that year 5 heifers produced 249 kg 305-day FCM, higher than 2nd parity cows. This was due to an unexpected high milk fat content of year 5 heifers.

In Trial 1, after lactation stage 1, milk fat content significantly declined from parity 2 to parities subsequent to parity 4 while milk protein content increased slightly from parity 2 to parity 4. In Trial 2, on the other hand, as forementioned, year 5 heifers produced milk with a higher fat content than other parity groups. However, cows subsequent to parity 2 produced milk significantly higher in protein content than heifers. These conflicting results and those in the literature are difficult to interpret. Results reviewed by Crabtree (1984) showed that milk fat and milk protein contents declined with age (for 305-day lactation

averages). Korver (1982) noted that both milk fat and milk protein content increased from parity 2 to 3 then declined in one trial but not in another (for lactation weeks 1-12, 13-18 and 1-40). Strickland and Broster (1981) also observed that cows produced more fat content than heifers in weeks 3-10 and 1-43 of lactation.

It would therefore appear that stage of lactation can influence these observations. One would expect older cows to produce milk with more fat in early lactation than younger cows due to their ability to mobilize more body fat into milk (Flatt et al, 1969; Lodge et al, 1975), and also to produce milk with more protein content in all lactation stages since they would not be storing extra protein in body tissues as borne out in both trials of this work.

The declining milk fat content (Trial 1) with age would tend to infer that at the plateau of body fat mobilization there may be a shift in the balance of fatty acid deposition and mobilization to deposition resulting in less substrates for mammary lipogenesis. The degree of this shift may depend on body fat mobilization. Some credence to this hypothesis is provided by results of cows which calved in year 3. These animals mobilized body fat to produce 49.8 g/kg milk fat in lactation weeks 2-6, but were producing only 39.3 g/kg in lactation weeks 13-18 (Appendix Table A.20). This mode of action was probably involved in the unadjusted milk fat content illustrated in Figure 4.11. At lactation week 10, calving condition score groups (see Chapter 2) CS_2 (medium condition) and CS_3 (fat) animals continued to decline in milk fat content while CS_1 (thin) animals continued to increase in this trait. If the suggestions of Brown et al (1981) are accepted then increasing milk yield with age will also result in less available energy for fat synthesis; this does not, however,

explain the milk fat pattern of CS groups since milk yields differed little between the groups (Figure 4.9).

4.2.2.3 Effect of Milk Yield

The classification of animals into milk yield groups (Chapter 2.8), based on daily milk yield in lactation week 2, tends to support the view that this is a good index for allocating animals into milk yield potential groups (Johnson, 1977; Strickland and Broster, 1981). However, it appears not to be a precise index for predictive purposes. This is evidenced by the declining differences between low (MY_1) and high yielders (MY_3) in milk yield as lactation progressed (Figures 4.5 and 4.6). Thus differences between MY_1 and MY_3 declined from 7 kg/day (20%) in lactation stage 1 to only 2.1 kg/day (7.8%) in lactation stage 4 and was 770 kg (10.2%) over 305 days of lactation. This is further reflected in the declining regression coefficients of average daily milk yield (in stage of lactation) on daily milk yield in lactation week 2 (Appendix Table A.19). This is less surprising when it is remembered that correlation coefficients between daily milk yields in lactation stage 1 (weeks 2-6) with those in other stages were smaller than those between milk yields in the other stages of lactation (Appendix Table A.16).

It is not clear if this pattern of milk yield difference between low and high yielders is due to the longer time to peak yield and higher persistency of low compared to high yielders (Broster and Broster, 1984). The pattern of concentrate allocation in this investigation could also have influenced differences. Declining concentrate to forage ratios depress milk yields more in high than low yielders (Phipps et al, 1984b). It is also possible that some animals with low yields in lactation week 2, due probably to post-partum stress, tend later to have higher yields than

normal.

The present results are, however, in line with observations of Johnson (1979). He classified cows into 2 potential milk yield groups based on mean daily milk yields in days 8-12 of lactation and observed that high yield groups produced more milk than low yield groups but the differences declined as lactation progressed. Also Davey et al (1983), using cows of high and low breeding index, noted that milk fat yield differences increased in one experiment but not another. Differences were attributed to greater partitioning of dietary energy to milk energy by high yielders compared to low yielders.

Daily milk yield in lactation week 2 showed no significant correlation with milk composition. This is in contrast to results of Johnson (1979) who observed that low yielding cows gave milk with a higher fat content but not protein content than high yielding cows. Oldham and Sutton (1979) demonstrated that cows capable of producing high yields are likely to produce milk low in protein content.

The lack of significant effect of milk yield on milk composition in the present experiment could be due to the ad libitum feeding of high energy complete diets resulting in high feed intakes. It was expected that high yielding cows would produce milk low in fat and protein due to competition between milk yield and milk composition for available energy, and the use of dietary protein, for gluconeogenesis, to provide substrates for lactose synthesis especially in early lactation during negative energy balance (Armstrong, 1982).

4.2.2.4 Milk Yield (MY) x Calving Condition Score (CS) Interaction

Cowan (1982) suggested that increased CS will have no beneficial effect

on the milk yield of high yielding cows due to their greater appetites but might benefit low yielding cows because of their low appetites. It could also be argued that since high yielding cows draw more heavily on body reserves in early lactation than low yielding cows (Broster, 1976), they should respond more positively in milk yield to increased CS.

It would appear that under ad libitum feeding none of these suggestions are important. Cows differing in genetic merits (measured as breeding index) at the same CS did not indicate large differences in rate of mobilization of body reserves in early lactation. However, over the whole lactation high breeding index cows had favourable partition of energy producing more milk fat and gaining less weight and condition score (Bryant, 1981; Davey et al, 1983). Also, in the present experiment no difference was observed between low and high milk yield groups on the effect of CS on milk yields.

In contrast, to this consensus of results, Neilson et al (1983) using part of the present data set demonstrated an interaction between milk yield and calving backfat area on milk energy yield. Differences between this study and the current investigation could be due to two reasons. Firstly, these authors classified their animals based on actual average milk yields over the experimental period and, secondly, the number of animals in some of these classes were small (less than 10 animals). Errors in recording in cases of few observations can give misleading results.

The significant interaction of parity and CS (Trial 2) on milk fat content (lactation stage 3) and milk protein content (lactation stage 1) are complex and difficult to evaluate. Milk fat and protein contents tended to be depressed by increasing CS for cows. This was unexpected since

increasing body fat content at calving is known to result in increased milk fat content (see Broster and Broster, 1984). Presumably these animals mobilized large amounts of body fat, in early lactation, into milk fat thus shifting the balance between fat mobilization and fat deposition towards fat deposition as previously suggested. Depressed milk protein content with increasing CS was undoubtedly a reflection of low feed intakes (thus low energy and protein intakes) by fat cows at this time. This would result in a shortage of dietary and microbial protein for gluconeogenesis and milk protein synthesis (Oldham, 1984; Thomas, 1984).

4.2.2.5 Main Effects of Calving Condition Score (CS)

With the above calving CS x parity interaction providing difficult interpretative challenges, it is not surprising that no significant effect of CS on milk production traits was observed. Also another confusing aspect of the present results was the contrasting results of this factor on milk production traits from the 2 trials. Trial 1 observed a slight positive effect and Trial 2 a slight negative effect.

Several experiments, however, have found significant increase in milk yield for cows calving in better than thin conditon (Land and Leaver, 1980; Grainger et al, 1982; see Reviews by Grainger and McGowan, 1982; Broster and Broster, 1984).

The results of Trial 1 are in line with observations of Boisclair et al (1984) who could not show a significant effect of CS on milk yields and composition. While the results of Trial 2 are in agreement with the observations of Frood and Croxton (1978) and Garnsworthy and Topps (1982b) who demonstrated that thin cows produced slightly more milk

and milk fat content than fat cows.

Some explanations have been suggested for the discrepancies in the results published. Broster and Broster (1984) have acknowledged that there may be an optimum CS about 3.0-3.5 above which there is no milk yield advantage. No such optimum CS was observed in the present experiment even though a wide range CS were covered. Whereas Garnsworthy and Topps (1982b) argued that where high energy diets are fed ad libitum thinner cows achieve higher intakes and milk yields than fat cows.

There is, however, enough available evidence for a third explanation to show that the effect of CS is on milk fat rather than milk yield per se and occurs only in cases of CS loss and liveweight loss. In a review of the literature on pre-partum feeding or condition of the animal at calving on milk production, Kirchgessner et al (1967), Broster (1971) and Grainger and McGowan (1982) have concluded that the beneficial effects of high level of pre-partum feeding or better condition at calving on milk production are more marked during underfeeding. Also Grainger et al (1982) fed cows, calving in different condition scores, 3 different levels of feed dry matter (8, 11 and 14 kg/day). In weeks 0-5 of lactation the low level fed animals lost more condition and produced more milk fat content but slightly less milk and milk fat yields. In the present investigation liveweight change influenced milk fat content and FCM yield in lactation weeks 2-6. Deleting liveweight change from the model did not alter the level of significance of CS on milk production traits. This suggests that under ad libitum feeding, if physical mechanisms do not influence VFI, increasing CS will have no significant influence on milk yields.

The negative effect of CS on milk production traits in Trial 2 could be due to the high partition of liveweight into FCM yield and milk fat content by heifers (year 5) than expected. Heifers were slightly thinner than cows subsequent to parity 2 in this trial.

4.2.2.6 Effect of Liveweight

The absence of any effect of liveweight at calving on milk production traits is in contrast to the results of previous experiments (Schmidt and Van Vleck, 1974; Brown et al, 1977; Kover, 1982) in which significant positive relationships between calving liveweights and milk yields were found. In these experiments, however, parity differences were not accounted for and this could have resulted in the significant relationships noted. For example, Donker et al (1983) noted that cows which had mean liveweights of 525 and 570 kg at calving in the second lactation were not different in milk yields. Furthermore, Brown et al (1981) have cautioned the use of both liveweight and age or parity in milk yield models due to the fact that these factors are confounded and are not independent variables.

These results would therefore tend to imply that within parity liveweight is not an important factor on milk production. This may not be the case for 1st calvers, where calving liveweight has significant influence on milk yield (Fisher et al, 1983).

4.2.2.7 Effect of Liveweight Change (LWC)

Broster (1976) showed that the cow divides her feed, maintenance needs apart, between milk and liveweight and does this over a range of levels of feed. Thus an increase in the level of feed intake leads to more liveweight gain as well as milk yield and a reduction in feed intake

causes a fall in both. There is therefore a negative linear relationship between LWC and milk yield. This then suggests that the high yielding cow preferentially produces more milk from a given amount of feed compared to the low yielding cow and she does it at the expense of body reserves. Demonstration of this point can be obscured by feeding procedures whereby the high yielding cow is awarded more feed than the low yielder (Broster, 1974).

Broster et al (1969, 1975) with heifers on fixed level of feeding demonstrated a significant inverse relationship between LWC and milk yield in different stages of lactation. While Johnson (1977) with cows also on fixed level of feeding could not find any significant negative association between LWC and milk. In line with these observations the current experiment unequivocally showed a significant inverse relationship between these 2 traits for cows and heifers (Trial 2) but not for cows only (Trial 1). These results suggest that the parity of animals used and probably the level of feeding applied affect the magnitude of these relationships.

No evidence has been found in the literature on the effect of ad libitum feeding on the inverse association between LWC and milk yield. Ostergaard (1979) and Gordon (1984) found no difference between high and low yielders in milk yield response to a unit change in concentrate when good quality forage was fed ad libitum. This implies lack of significant association between LWC and milk yield under this system of feeding.

Also, heifers due to a drive towards growth will be expected to partition some of their feed into growth rather than milk yield resulting in

significant inverse association between these 2 variables, while cows in early lactation will partition liveweight loss into milk fat and thus FCM yield resulting in significant inverse relationships between LWC and milk fat and FCM yield but not with milk yield, as was observed. Later in lactation, under ad libitum feeding, LWC increased, feed intake increased but milk yield declined (following on the typical lactation curve) leading to a negative but not significant relationship between LWC and milk yield.

Increasing LWC was associated with a significant increase in milk protein content. Similar results have not been reported for comparative purposes. It would, however, be expected that a cow in negative energy balance will partition its protein intake and protein reserves for gluconeogenesis to provide energy for milk synthesis resulting in milk of low protein content. An animal in positive energy balance, on the other hand, is liable to increase its protein synthesis into milk by the reduction of the uptake of amino acids for gluconeogenesis (Armstrong, 1982).

4.3 Conclusion

In a 24-week experiment beginning at week 2 post-partum, the influence of various environmental (years and months of calving) and animal (parity, LWC, daily milk yield in lactation week 2 and calving condition score and calving liveweight) factors on milk yields and composition of only cows (Trial 1) and of cows and heifers (Trial 2) producing 7236 and 7656 kg and 6621 and 7051 kg 305-day milk and FCM yields respectively were studied.

The results indicated no significant ($P < 0.05$) influence of calving condition

(CS) on milk yields or composition. There was, however, a tendency for milk protein content to decline with increasing CS. The results also implied that fat cows which mobilize large amounts of body fat into milk fat early in lactation have, later in lactation, a change in partition of nutrients towards body condition rather than milk fat resulting in milk fat depression. This, however, needs confirmation from designed experiments. There was no significant interaction between daily milk yields in lactation week 2 and CS on subsequent lactation milk yields and composition.

LWC was inversely associated with daily and 305-day milk and FCM yields and milk fat content, but was positively associated with milk protein content. The inverse relationship between LWC with milk yield reached statistical significance only in Trial 2. This implies the importance of a high plane of nutrition to sustain both growth and production for 1st calvers.

Daily milk yield in lactation week 2 showed a predictable strong and positive correlation with milk yields in subsequent weeks of lactation. This strong correlation, however, tended to decline as lactation progressed. This factor had no significant association with milk composition in subsequent weeks of lactation.

Predictably, heifers produced less milk than cows. The same animal produced 11.2 and 12.0% less milk and FCM in 305 days of lactation as a heifer than as a 2nd calver. Cows subsequent to parity 2 produced more milk protein content than heifers. Also, increasing CS significantly depressed milk protein content (lactation stage 1) for cows but not for heifers.

There was no difference between years of calving or between cows calving from September to December in milk yields, an indication of either adequate nutrient supply or that the inclusion of LWC removed most of these effects.

Correlations between 305-day milk yields in consecutive lactations of the same cow were moderate (r = 0.42-0.58).

In conclusion, this experiment confirmed that under ad libitum feeding of high energy complete mix diets increasing CS does not result in a significant ($P < 0.05$) increase in milk yields and composition. There is therefore no advantage in milk yields and milk composition with increasing CS for any milk yield potential group. Also, although the evidence is inconclusive, CS depresses milk protein content. These results also confirm the inverse relationship between milk yield and LWC. Milk fat and milk protein contents are increased under conditions of liveweight loss and liveweight gain respectively. Daily milk yield in lactation week 2, although not a precise predictor of milk yield later in lactation, is a good index for allocating animals into milk yield potential classes in 24 weeks of lactation. Under the present system of feeding and management milk yield in 305 days of lactation is a fair to moderate index for allocating cows into milk yield potential classes for the next lactation. No additional precision is introduced by using both parity and LW in the same analysis of variance models for milk production traits. Animals fed 11.5 MJ ME/kg DM complete mixed diet are capable of producing 36 kg/day peak milk. The genetic potential of heifers at Langhill farm is improving as borne out by high 305-day milk and FCM yields (6815 and 7554 kg respectively) of year 5 heifers of this experiment and the higher milk yields of the selected versus the control herds shown in Table 4.11.

Table 4.11 Comparison of 305-day milk yields and milk composition of selected and control heifers at Langhill Farm (years 1980/81 and 1983/84).

	Milk yield (kg)	Fat (g/kg)	Protein (g/kg)
Year 1983/84			
Selected heifers (n=34)	6678	43.6	34.0
Control heifers (n=7)	5484	43.3	34.0
Control + selected heifers (n=41)	6474	43.5	34.0
Year 1980/81			
Control + selected heifers (n=42)	5618	42.9	35.0

5 ENERGY AND NITROGEN UTILIZATION

5.1 Results

5.1.1 GENERAL

Means and standard deviations for nutrient utilization traits are provided in Tables 5.1 and 5.2 for Trials 1 and 2 respectively. In conformity with the usual pattern of nutrient intake and utilization daily intakes of ME increased with advancing lactation reaching maximum values in lactation stage 2 (weeks 7-12). Energy requirements were, however, highest (103.2 and 84.4 MJ/day for Trials 1 and 2 respectively) in lactation stage 1 (weeks 2-6). Thus cows, on average, were estimated to be in negative energy balance (23.0 MJ ME/day) for Trial 1, but in positive energy balance (5.2 MJ ME/day) for Trial 2 in lactation stage 1. Gross and net efficiencies and nitrogen efficiency were high at this time and were 0.51, 0.71 and 0.37 for Trial 1, and 0.43, 0.58 and 0.30 for Trial 2. Using the New Protein System for ruminants (ARC, 1980, 1984) the animals were estimated to be retaining on average 1.8 and 25.7 g/day essential amino acid-N respectively for Trials 1 and 2 (Appendix Table A.24).

As lactation progressed, intakes of ME and nitrogen increased above requirements while gross efficiency, net efficiency and nitrogen efficiency declined. Also, ME intake in excess of maintenance requirements per kg FCM and concentrate intake per kg milk yield increased (Appendix Table A.24). Thus by lactation stage 4 (weeks 19-24) animals were estimated, on average, to be in positive energy balance (24.6 and 32.3 MJ ME/day for Trials 1 and 2 respectively) and were consuming 114.5 and 119.7% of ME requirements. Gross, net and

nitrogen efficiencies had declined to 0.37, 0.51 and 0.26 and 0.35, 0.48 and 0.26 respectively for Trials 1 and 2. The largest decline in energetic efficiencies was between lactation stages 1 and 2 (8.1-14.2 and 4.1-7.2% units for Trials 1 and 2 respectively).

Correlations between the same nutrient utilization trait in one stage of lactation and the next stage of lactation declined as the time between stages increased (Appendix Table A.25). Within cow correlations between energy balance and between net efficiency in the same stage of lactation in consecutive lactations were small and ranged from 0.165 and 0.172 (lactation stage 1) to 0.486 and 0.374 (lactation stage 4) (Appendix Table A.26) respectively.

5.1.2 EFFECTS OF DIFFERENT FACTORS ON ENERGY AND NITROGEN UTILIZATION TRAITS

The effects of different factors on energy utilization traits (estimated ME intake, estimated energy balance, gross and net efficiencies) and nitrogen efficiency were tested by analysis of variance. Model 1, which included the factors years and months of calving, parity, daily milk yield in lactation week 2 (MY), calving condition score (CS), MY x CS, calving liveweight, weekly weight change in the stage of lactation, explained 19.3-69.0% of the total variation in these traits, in various stages of lactation for Trial 1 (Table 5.1). Likewise, Model 2 which included all these factors except years of calving and MY x CS accounted for 20.8-74.4% of the total variation in these traits for Trial 2 (Table 5.2). The effectiveness of the models in explaining variation in these traits declined as lactation progressed. The associated least squares means for these traits for Trial 1 are given in Tables 5.3-5.7 and Appendix

Table 5.1 Means, standard deviations (SD) and residual standard deviations (RSD) of energy and nitrogen utilization traits per stage of lactation - TRIAL 1

TRAIT	Mean	SD	RSD	R^2(%)*
Estimated metabolizable energy (ME) intake (MJ/day)				
Stage 1	205	23.0	18.7	61.9
2	233	28.4	23.0	43.3
3	228	29.0	24.9	36.3
4	211	26.4	20.9	45.3
1-4	220	23.6	18.1	49.2
Maximum ME intake (MJ/day)	265	30.2		
Estimated energy balance (MJ ME/day)				
Stage 1	-23.0	36.0	21.6	69.0
2	12.4	32.5	28.6	33.3
3	26.6	29.2	25.8	33.3
4	24.6	25.6	23.1	30.1
1-4	11.0	23.8	17.9	51.1
Gross efficiency (%)				
Stage 1	50.9	10.0	6.0	69.0
2	42.8	7.3	6.4	33.9
3	38.1	6.2	5.6	29.6
4	36.7	6.4	7.0	25.5
1-4	41.7	5.8	4.3	52.3
Net efficiency (%)				
Stage 1	70.9	16.5	10.1	68.0
2	56.7	10.4	9.1	35.0
3	51.3	9.1	8.2	29.6
4	50.8	8.9	8.2	27.5
1-4	56.4	8.0	6.1	51.0
Nitrogen efficiency (%)				
Stage 1	36.7	5.0	3.9	48.1
2	30.4	4.3	4.2	19.3
3	27.8	4.0	3.8	23.4
4	26.4	4.3	4.0	26.8
1-4	30.0	3.4	3.0	34.6

* Variation accounted for by Model 1

Table 5.2 Means, standard deviations (SD) and residual standard deviations (RSD) of energy and nitrogen utilization traits per stage of lactation - TRIAL 2

TRAIT	Mean	SD	RSD	R^2(%)*
Estimated metabolizable energy (ME) intake (MJ/day)				
Stage 1	195	26.3	14.2	74.4
2	217	27.5	16.7	67.4
3	217	23.6	16.4	57.7
4	205	22.9	17.1	50.6
1-4	209	22.6	13.9	66.8
Maximum ME intake (MJ/day)	239	27.4		
Estimated energy balance (MJ ME/day)				
Stage 1	5.2	23.2	17.3	50.6
2	26.3	19.7	17.7	28.6
3	35.9	18.9	16.5	32.5
4	32.3	20.6	18.2	30.8
1-4	25.4	15.8	13.4	36.3
Gross efficiency (%)				
Stage 1	43.0	7.0	4.6	62.2
2	38.9	4.9	3.9	43.1
3	36.0	4.9	4.2	36.7
4	35.4	5.5	4.7	35.5
1-4	38.2	4.6	3.2	56.9
Net efficiency (%)				
Stage 1	58.5	9.6	7.3	49.2
2	51.3	6.5	5.6	34.5
3	47.7	6.4	5.6	32.6
4	48.1	7.2	6.2	35.3
1-4	51.0	5.8	4.6	45.9
Nitrogen efficiency (%)				
Stage 1	30.8	4.4	3.0	58.9
2	28.0	3.6	2.7	48.5
3	27.1	3.8	3.2	38.6
4	26.9	3.9	3.6	20.8
1-4	27.9	3.2	2.2	59.8

* Variation accounted for by Model 2

Table 5.3 Least squares means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily estimated energy intake (MJ ME) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	195	3.2	224	3.9	222	4.2	209	3.6	213	3.1
Parity											
2	26	193	5.4	216	6.7	211	7.3	210	6.2	208	5.3
3	34	191	4.2	222	5.3	223	5.6	208	4.8	211	4.2
4	25	199	4.5	231	5.7	227	6.1	209	5.1	217	4.4
5	30	196	4.4	228	5.5	226	6.0	207	5.0	216	4.3
R^2		1.4		3.3		3.0		0.1		1.7	
Condition score groups											
1	65	209[a]	3.7	237[a]	4.6	232	5.0	210	4.2	221	3.6
2	26	202[a]	4.1	230[a]	5.1	223	5.5	210	4.6	217	4.0
3	24	173[b]	7.8	207[b]	9.7	211	10.5	206	8.8	201	7.6
R^2		5.7		5.5		3.2		1.8		3.2	
Weight change (b,SE)	115	2.398	0.3253**	2.145	0.6539**	1.644	0.7971*	0.7421	0.6580	3.247	0.9521**
R^2		17.9		5.1		2.3		0.4		4.9	
Calving liveweight (b,SE)	115	0.1399	0.0182**	0.0819	0.0527	0.1350	0.0572*	0.1732	0.0480**	0.1426	0.0423**
R^2		2.8		3.7		3.8		1.9		5.8	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 5.4 Least squares means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily estimated energy balance (MJ ME) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	-25.1	3.67	9.2	4.85	23.3	4.37	23.6	3.91	7.5	3.05
Parity											
1	26	-17.1^{a}	6.22	2.9	8.22	11.1	7.48	18.3	6.69	1.9^{a}	5.22
3	34	-34.7^{b}	4.91	4.5	6.54	25.3	5.82	24.0	5.22	3.2^{ac}	4.28
4	25	-21.0^{ac}	5.51	11.9	6.82	31.8	6.16	32.3	5.51	16.4^{b}	4.28
5	30	-27.8^{c}	4.95	7.6	6.57	25.1	5.94	20.0	5.28	8.6^{c}	4.14
R^2		2.2		3.6		3.2		2.5		2.8	
Condition score groups											
1	65	-14.0^{a}	4.98	21.8	5.28	35.6	4.65	25.5	4.17	15.3^{a}	3.29
2	26	-16.2^{a}	4.83	14.0	6.42	27.8	5.75	29.1	5.16	12.5^{a}	4.04
3	24	-45.4^{b}	8.79	-8.0	11.80	6.7	10.51	16.4	9.37	-5.2^{b}	7.29
R^2		4.7		6.0		2.6		1.5		5.1	
Weight change (b,SE)	115	3.245	0.3752**	3.110	0.8142**	2.402	0.8205**	1.143	0.7173	6.216	0.9345**
R^2		1.1		1.0		1.7		2.9		2.8	
Calving liveweight (b,SE)	115	0.0669	0.0328*	0.0122	0.0428	0.0542	0.0385	0.0687	0.0345*	0.0682	0.0271*
R^2		1.1		1.0		1.7		2.9		2.8	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 5.5 Least squares means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for gross efficiency (%) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	51.7	1.02	43.1	1.09	38.4	0.96	36.7	1.02	42.3	0.74
Parity											
2	26	49.3[a]	1.75	44.3	1.87	40.6	1.65	38.1	1.77	43.2	1.26
3	34	54.2[b]	1.36	44.0	1.46	38.1	1.27	36.4	1.35	43.4	0.98
4	25	51.0[a]	1.45	40.7	1.55	36.7	1.36	34.6	1.44	40.6	1.03
5	30	52.4[b]	1.45	43.3	1.56	38.3	1.35	37.7	1.45	42.2	1.04
R^2		2.4		2.3		2.6		2.5		2.0	
Condition score group											
1	65	47.9[a]	1.15	40.7	1.25	36.1	1.08	35.9	1.15	40.3	0.82
2	26	48.9[a]	1.35	41.7	1.45	37.2	1.26	35.2	1.35	41.0	0.97
3	24	58.4[b]	2.52	46.8	2.70	42.1	2.37	39.0	2.50	45.7	1.79
R^2		5.4		6.2		5.1		3.7		6.1	
Weight change (b,SE)	115	-0.8822	0.1052**	-0.6632	0.1823**	-0.4850	0.1836**	-0.2280	0.1854	-1.518	0.2251**
R^2		19.6		7.8		4.4		1.1		19.5	
Calving liveweight (b,SE)	115	-0.0309	0.0138*	-0.0013	0.0143	-0.0113	0.0127	-0.0183	0.0134	-0.0250	0.0098*
R^2		1.4		0.6		0.8		1.7		2.0	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 5.6 Least squares means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for net efficiency (%) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	73.9	1.72	57.6	1.54	52.1	1.40	50.9	1.39	57.7	1.04
Parity											
2	26	70.5	2.94	59.8	2.64	56.2	2.41	52.6	2.41	59.1	1.78
3	34	77.7	2.28	58.9	2.06	51.7	1.84	50.7	1.85	59.2	1.39
4	25	72.5	2.43	54.1	2.19	49.4	1.98	48.0	1.97	55.0	1.46
5	30	75.0	2.69	57.7	2.2	51.3	1.98	52.2	1.98	57.3	1.47
R^2		2.2		2.6		3.3		2.4		2.3	
Condition score groups											
1	65	66.2[a]	1.93	53.6	1.76	48.8	1.58	50.2	1.57	54.4[a]	1.16
2	26	68.3[a]	2.27	55.4	2.05	50.9	1.84	48.9	1.84	55.7[a]	1.37
3	24	87.2[b]	4.21	63.8	3.81	56.7	3.45	53.5	3.42	62.8[b]	2.53
R^2		6.7		6.9		4.1		2.4		5.9	
Weight change (b,SE)	115	-1.476	0.1765**	-0.9663	0.2576**	-0.7747	0.2674**	-0.3677	0.2532	-2.070	0.3174**
R^2		20.2		8.3		3.2		1.4		18.8	
Calving liveweight (b,SE)	115	-0.0319	0.0232	0.0078	0.0203	-0.0069	0.0184	-0.0266	0.0183	-0.0266	0.0139
R^2		0.6		0.3		0.4		1.6		1.2	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 5.7 Least squares means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for nitrogen efficiency per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	35.9	0.66	30.6	0.71	28.4	0.64	27.0	0.68	30.4	0.51
Parity											
2	26	33.2[a]	1.13	30.0	1.22	29.0	1.11	27.5	1.18	30.0	0.87
3	34	37.3[b]	0.88	31.0	0.95	28.2	0.85	26.5	0.90	30.8	0.68
4	25	35.9[c]	0.93	30.0	1.01	27.4	0.91	25.9	0.97	29.8	0.72
5	30	37.4[b]	0.94	31.4	1.01	29.0	0.91	28.0	0.96	31.0	0.72
R^2											
Condition score groups											
1	65	34.4[a]	0.74	28.9	0.81	26.9	0.73	25.8	0.77	29.1	0.57
2	26	35.3[a]	0.87	30.7	0.94	28.0	0.84	26.0	0.90	30.1	0.67
3	24	28.1[b]	1.62	32.2	1.75	30.4	1.59	29.1	1.67	32.1	1.24
R^2		7.6		4.1		4.0		4.0		5.2	
Weight change (b,SE)	115	-0.2834	0.0679**	-0.2138	0.1188	-0.1736	0.1229	-0.0967	0.1235	-0.6625	0.1557**
R^2		8.1		2.4		1.4		0.4		10.6	
Calving liveweight (b,SE)	115	-0.0268	0.0089**	-0.0172	0.0094	-0.0164	0.0085	-0.0173	0.0089	-0.0243	0.0068**
R^2		4.2		4.1		3.2		3.2		6.3	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 5.8 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score (1-5 units) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily estimate energy intake (MJ ME) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	0.8419	0.5126	1.750	0.8979	1.979	0.9345*	3.028	0.1192*	1.778	1.300
R^2		0.8		2.1		3.4		5.3		1.5	
Calving liveweight (b,SE)	75	0.1352	0.0475**	0.1666	0.0554**	0.1226	0.0528*	0.0953	0.0563	0.1350	0.0458**
R^2		2.9		2.8		1.6		2.1		2.6	
Calving condition score (b,SE)	75	-18.85	8.241*	-26.07	9.865**	-9.655	9.548	-14.13	9.983	-16.31	8.066*
R^2		1.9		2.3		0.6		1.5		1.6	
Parity groups											
1a	24	173^a	4.9	195^a	5.6	202^a	5.7	196^a	5.7	192^a	5.2
1b	25	181^b	4.8	203^b	5.5	205^a	5.6	194^a	5.6	196^a	5.1
2	14	222^c	6.6	235^c	7.4	226^b	7.6	204^b	7.6	222^b	6.9
3	12	224^c	6.8	254^d	7.7	245^c	5.6	231^c	8.0	239^c	7.2
All	75	195	2.9	217	3.3	217	3.4	205	3.4	209	3.1
Level of significance		***		***		***		***		***	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 5.9 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score (1-5 units) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for daily estimated energy balance (MJ ME) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	2.624	0.6220**	3.894	0.9522**	3.732	0.9431**	3.740	1.267**	5.985	1.257**
R^2		13.0		17.6		15.5		8.8		21.3	
Calving liveweight (b,SE)	75	0.0319	0.0554	0.1239	0.0566*	0.0180	0.0514	-0.0140	0.0578	0.0642	0.0426
R^2		0.3		2.0		0.0		0.1		0.6	
Calving condition score (b,SE)	75	-11.67	10.10	-20.91	10.46*	8.60	9.62	10.07	10.63	-2.774	7.820
R^2		1.1		1.7		0.3		0.5		0.1	
Parity groups											
1a	24	11.4[a]	2.64	26.4	3.99	37.4	3.69	34.4[a]	3.93	27.9	3.18
1b	25	10.7[a]	5.92	23.6	3.92	28.9	3.62	24.2[b]	3.85	22.2	3.12
2	14	-5.9[b]	5.92	28.7	5.33	39.9	4.94	25.8[b]	5.25	24.6	4.25
3	12	-5.6[b]	6.14	28.9	5.53	40.7	5.12	31.8[a]	5.45	27.6	4.41
All	75	5.2	2.64	26.9	2.38	35.9	2.2	32.3	2.34	25.6	1.89
Level of significance		*		NS		NS		*		NS	

[abcd] Different superscripts in column indicate significant difference $P < 0.05$

* = $P < 0.05$, ** $P < 0.01$, NS = not significant

Table 5.10 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score (1-5 units) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for gross efficiency (%) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.8098	0.1652**	-1.016	0.2114**	-0.8483	0.2388**	-0.8378	0.3262*	-1.856	0.3011**
R^2		13.4		12.9		10.9		6.2		24.1	
Calving liveweight (b,SE)	75	-0.0232	0.0153	-0.0426	0.0130**	-0.0124	0.0135	-0.0072	0.0154	-0.0308	0.0106**
R^2		1.3		5.9		1.1		1.3		3.2	
Calving condition score (b,SE)	75	3.524	2.656	4.316	2.323	-2.280	2.440	-3.204	2.732	0.6101	1.868
R^2		1.0		1.0		0.4		1.0		0.0	
Parity groups											
1a	24	39.7	1.26	36.9	0.96	34.2^a	0.95	33.8^a	1.04	35.8^a	0.88
1b	25	41.8	1.24	39.7	0.94	38.0^b	0.94	38.0^b	1.02	39.2^b	0.86
2	14	47.9	1.69	41.0	1.28	40.2^c	1.28	39.3^c	1.39	41.7^c	1.17
3	12	46.6	1.75	40.0	1.33	35.5^a	1.32	34.3^a	1.44	38.9^b	1.22
All	75	43.0	0.75	38.9	0.57	36.0	0.57	35.1	0.62	38.2	0.48
Level of significance		NS		NS		*		*		*	

abcd Different superscripts in column indicate significant difference

* = $P < 0.05$, ** $P < 0.01$, NS = not significant

Table 5.11 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight and condition score (1-5 units) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for net efficiency (%) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-1.146	0.2639**	-1.375	0.2997**	-1.203	0.3206**	-1.308	0.4304**	-2.320	0.4269**
R^2		14.1		20.3		13.9		8.8		23.5	
Calving liveweight (b,SE)	75	-0.0232	0.0245	-0.0509	0.0185**	-0.0088	0.0181	0.0006	0.0020	-0.0328	0.0151*
R^2		0.6		4.0		0.2		0.3		1.6	
Calving condition score (b,SE)	75	7.363	4.242	6.957	3.292*	-2.789	3.276	-3.961	3.599	1.769	2.648
R^2		2.2		1.8		0.3		0.8		0.2	
Parity groups											
1a	24	55.8	1.87	49.8	1.30	45.9[a]	1.26	46.2	1.37	48.7	1.14
1b	25	57.0	1.84	52.3	1.28	49.2[c]	1.23	51.6	1.34	52.4	1.12
2	14	62.7	2.50	52.7	1.74	50.6[c]	1.68	51.5	1.83	54.3	1.52
3	12	61.9	2.60	51.6	1.81	49.5[c]	1.74	50.7	1.89	53.3	1.58
All	75	58.6	1.12	51.3	0.78	47.7	0.75	48.1	0.81	51.2	0.68
Level of significance		NS		NS		*		NS		NS	

abcd Different superscripts in column indicate significant difference

* P = 0.05, ** P < 0.01, NS = not significant

Table 5.12 Unadjusted parity groups means, standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score (1-5 units) and liveweight change - kg/week (regression coefficients (b)) and the variance (R^2%) explained by each factor for nitrogen efficiency (%) per stage of lactation

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.3959	0.1084**	-0.5587	0.1455**	-0.4203	0.1815*	-0.4239	0.2504	-1.117	0.2033**
R^2		8.9		11.2		4.9		3.3		17.8	
Calving liveweight (b,SE)	75	-0.0163	0.0100	-0.0378	0.0090**	-0.0134	0.0102	-0.0003	0.0118	-0.0228	0.0072**
R^2		1.6		9.2		2.0		0.4		3.7	
Calving condition score (b,SE)	75	0.9621	1.743	6.021	1.598**	-0.3411	1.854	-1.801	2.097	1.359	1.261
R^2		0.1		7.7		0.0		0.6		0.05	
Parity groups											
1a	24	28.9^a	0.74	28.2^a	0.65	27.3^a	0.68	26.1	0.75	27.4^a	0.56
1b	25	28.8^a	0.73	27.6^a	0.64	26.7^a	0.67	26.5	0.73	27.2^a	0.54
2	14	35.2^b	0.99	30.4^b	0.87	28.5^b	0.91	27.5	0.99	30.2^b	0.75
3	12	34.5^b	1.03	31.1^b	0.90	29.9^c	0.94	27.8	1.04	31.6^c	0.78
All	75	30.8	0.44	28.0	0.39	27.1	0.41	26.8	0.44	27.9	0.78
Level of significance		**		*		*		NS		**	

abcd Different superscripts in column indicate significant difference

** = $P < 0.01$ * = $P < 0.05$ NS = not significant

Tables A.27-A.31. For results of Trial 2 the unadjusted parity group means and least squares means of the traits are provided in Tables 5.8-5.12 and Appendix Tables A.32-A.36.

As suspected, year of calving proved to be a most important factor causing significant differences ($P < 0.05$) between animals in all energy and nitrogen utilization traits. Year differences in ME intake in most stages of lactation were due to low feed intakes of cows calving in years 1 and 3 (Appendix Table A.27). This resulted in low estimated energy balance, but high gross and net efficiencies for these cows (Appendix Tables A.28-A.30). This trend, however, disappeared for nitrogen efficiency (Appendix Table A.31).

For results of Trial 1, but not Trial 2, significant differences ($P < 0.05$) occurred between months of calving in ME intake and energy balance in lactation stages 3 and 4. September calvers had higher ME intakes and energy balance whereas November-December calvers had low ME intakes and energy balance at these lactation stages. However, September calvers were surprisingly slightly less gross efficient than other monthly groups in converting energy intake into milk (Appendix Tables A.27-A.31).

Parity, in Trial 1, after adjustments of the data, turned out not to be an important factor influencing nutrient utilization traits except ($P < 0.05$) energy balance in lactation stage 1 and over stages 1-4 and gross and nitrogen efficiencies in lactation stage 1. Estimated energy balance tended to decline as cows advanced from 2nd through 3rd lactation resulting in 17 MJ ME/day difference between the two parities in lactation stage 1. However, after lactation stage 1 parity 2 animals

had lower estimated energy balance and were thus slightly more efficiency (gross) than subsequent parities (Tables 5.5-5.7).

For Trial 2, parity (except liveweight change) was the most important source of variation in energy and nitrogen utilization traits. Parity groups differed significantly not only in unadjusted means (Table 5.8) but also adjusted means (Appendix Table A.32) of daily ME intake. Heifers in year 5 had similar intakes of ME but had significantly ($P < 0.05$) higher gross efficiencies than heifers of year 4 in lactation stages 3 and 4 (Table 5.10 and Appendix Table A.34). For reasons given in Chapter 3 only the unadjusted means are discussed across parities. ME intake steadily increased ($P < 0.05$) as cows advanced from 1st through subsequent parities. Differences between cows and heifers in ME intake tended to decline as lactation progressed. For example, differencs in daily ME intake of the same animal as a heifer and as 2nd calver declined from 49 MJ (22.1%) in lactation stage 1 to 8 MJ (3.9%) in lactation stage 4. Parity groups also differed significantly ($P < 0.05$) in daily energy balance (lactation stages 1 and 4), gross efficiency (lactation stages 3 and 4), net efficiency (lactation stage 3) and nitrogen efficiency in all lactation stages except stage 4 (Tables 5.9-5.12). Efficiency traits, especially nitrogen and net efficiencies, were higher for cows than heifers. Surprisingly, energy balance and net efficiency of the same animal as a heifer and as a 2nd calver were not related (Appendix Table A.26) in any stage of lactation.

Differences between parity groups in unadjusted daily estimated energy balance and net efficiency are illustrated respectively in Figures 5.1 and 5.2. Higher efficiencies of cows than heifers (lactation weeks 2-18) are clearly illustrated. Also, it was only cows which mobilized body energy

in lactation weeks 2-8 (Figure 5.1).

Grouping cows by milk yield in lactation week 2 (MY) and calving condition score (CS) (see Chapter 2.8) resulted in a significant interaction ($P < 0.05$) between MY and CS on all energy and nitrogen utilization traits in lactation stage 1 for results in Trial 1. Least squares means of these variables classified by MY and CS groups are given in Appendix Table A.37. The trend, though not consistent, was for ME intake and energy balance within MY class to decline while gross and net efficiencies increase with increasing calving condition score. Individual MY group regressions of these variables on calving condition score were (b±SE):

ME Intake

- 31.77** ± 8.623; - 17.41** ± 6.991; - 6.342 ± 6.243 MJ ME/unit condition score

Energy Balance

- 27.87** ± 10.11; - 5.592 ± 8.221; - 7.965 ± 7.332 MJ ME/unit condition score

Gross Efficiency

8.714* ± 3.091; 0.9438 ± 3.019; 1.650 ± 2.239% units/unit condition score

Net Efficiency

18.63** ± 5.017; 3.793 ± 3.392; 3.647 ± 3.783% units/unit of condition score.

Nitrogen Efficiency

3.171 ± 2.023; 0.8081 ± 1.576; 2.091 ± 1.515% units/unit condition score; for MY 1, 2 and 3 respectively.

Where * = $P < 0.05$ and ** = $P < 0.01$.

All coefficients for nitrogen efficiency were non-significant. Also, only in MY 1 were most coefficients significantly different from zero.

As was anticipated, daily milk yield in lactation week 2 was an important factor, accounting for variation in all nutrient utilization traits for both trials. Increased milk yield in lactation week 2 was correlated with increased ME intake and efficiency traits, but with a decline in energy balance. The relationships between this trait and energy balance and efficiency were, however, only significant ($P < 0.05$) in lactation stage 1 for Trial 1, but in most stages of lactation for Trial 2 (Appendix Tables A.27-A.31 and A.32-A.36).

Figure 5.3 indicates the effects of milk yield groups (Trial 1) on unadjusted estimated energy balance. MY groups were consistently different in energy balance throughout the experimental period. However, irrespective of the milk yield group, on average, most animals were 7-19 weeks in negative energy balance. Net efficiencies below 62% (energy efficiency at zero energy balance, ARC, 1980) were therefore attained in weeks 8-20 (Figure 5.4).

Variations in nutrient utilization traits caused by calving condition score was largest in early lactation. Thus for Trial 1, after the MY x CS interaction in lactation stage 1, ME intake (lactation stage 2) and energy balance (over lactation stages 1-4) declined ($P < 0.05$) while gross and net efficiencies increased (over lactation stages 1-4). On average, animals in all condition score groups were in negative energy balance (unadjusted) for 12-21 weeks of lactation; this was highest for CS3 animals (fat) (Figure 5.5). This is an indication of a physiological drive in most high yielding cows to mobilize some body energy in early

lactation. Net efficiency (62%) at zero energy balance was attained in lactation weeks 13, 14 and 21 respectively for CS1, 2 and 3 (Figure.5.6). These values may, however, not reflect the exact effect of calving condition score due to confounding effects of other factors as milk yield levels.

Similarly, in results of Trial 2, increasing calving condition score was associated ($P < 0.05$) with a decline in daily ME intake (lactation stages 1 and 2), energy balance (lactation stage 2) but significant increase in net and nitrogen efficiencies (lactation stage 2) (Tables 5.8-5.12). Thus a unit increase in calving condition score was associated with 16.3-26.0 MJ/day decline in ME intake (Table 5.8).

As was expected, weekly weight change was the most important cause of variation in energy balance and efficiency traits for both trials. This influence, however, tended to decline as lactation progressed. In Trial 1, 1 kg increases in weekly weight change was associated ($P < 0.05$) with 1.6-3.2 and 2.4-6.2 MJ increase in ME intake and energy balance, but 0.49-1.52, 0.77-2.07 and 0.28-0.66% decline in gross, net and nitrogen efficiencies respectively (Tables 5.3-5.7). Likewise, in Trial 2, 1 kg increase in weekly weight change was equivalent to 0.9-3.0 and 2.6-6.0 MJ increase in ME intake and energy balance, but 0.81-1.86, 1.15-2.32 and 0.39-1.12% decline in gross, net and nitrogen efficiencies (Tables 5.8-5.12). The coefficients for Trial 2 were less variable between lactation stages than those of Trial 1.

Calving liveweight surprisingly accounted for only a small amount of the variation in energy and nitrogen utilization traits for both trials. This trait was positively associated ($P < 0.05$), however, with ME intake in

Figure 5.1 : Mean estimated energy balances(MJ ME/day) between weeks 2 and 24 of lactation for cows and heifers of year (YR) 4 and year 5:Adult Cows(.), Second calvers(o), YR4 Heifers(+), YR5 Heifers(x).

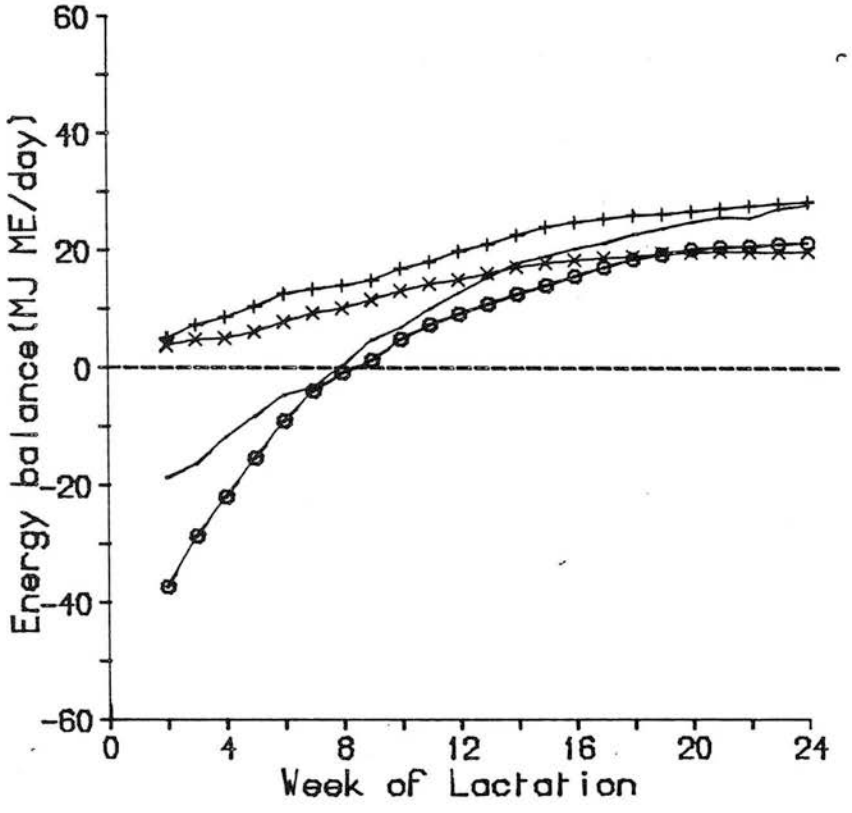


Figure 5.2 : Mean estimated net efficiencies(%) between weeks 2 and 24 of lactation for cows and heifers of year (YR) 4 and year 5:Adult Cows(.), Second calvers(o), YR4 Heifers(+), YR5 Heifers(x).

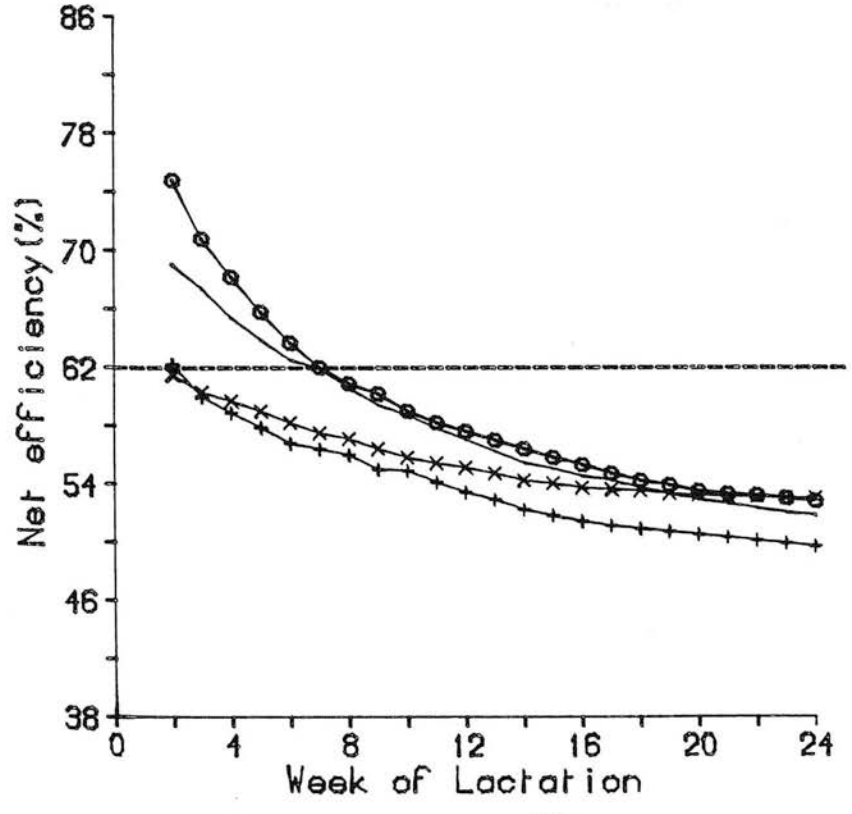


Figure 5.3 : Mean estimated energy balances(MJ ME/day) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

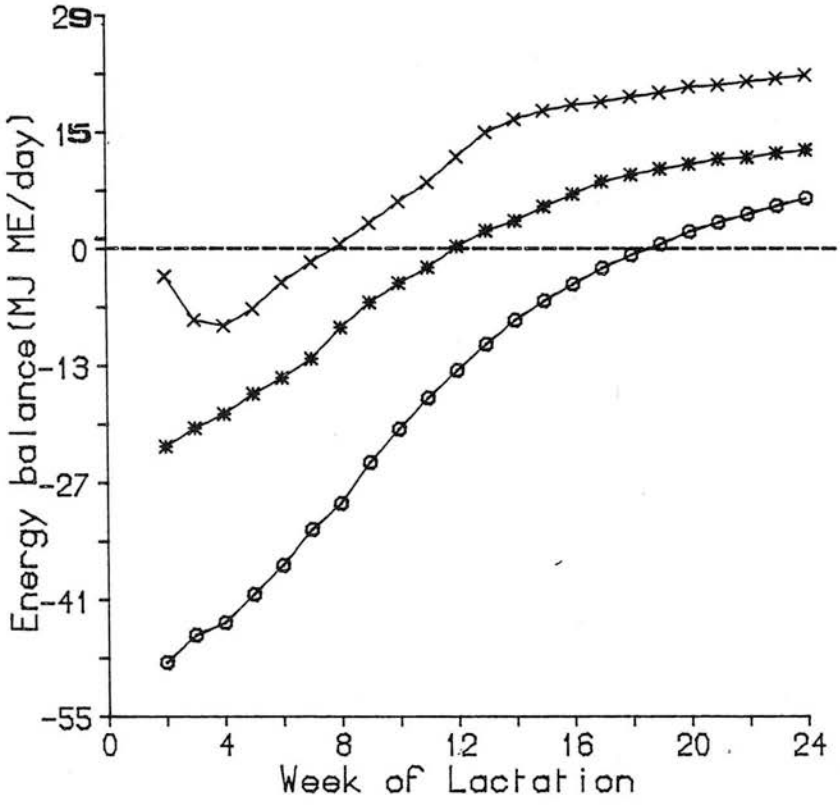


Figure 5.4 : Mean estimated net efficiencies(%) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

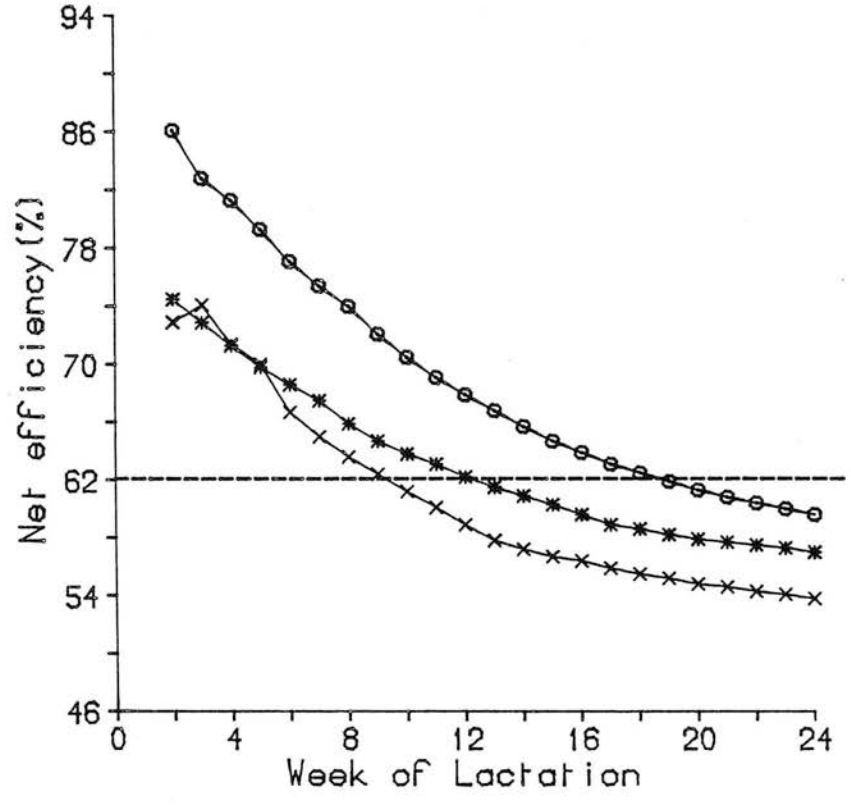


Figure 5.5 : Mean estimated energy balances(MJ ME/day) between weeks 2 and 24 of lactation for 3 condition score groups :CS1(thin,X),CS2(medium,*),CS3(fat,o).

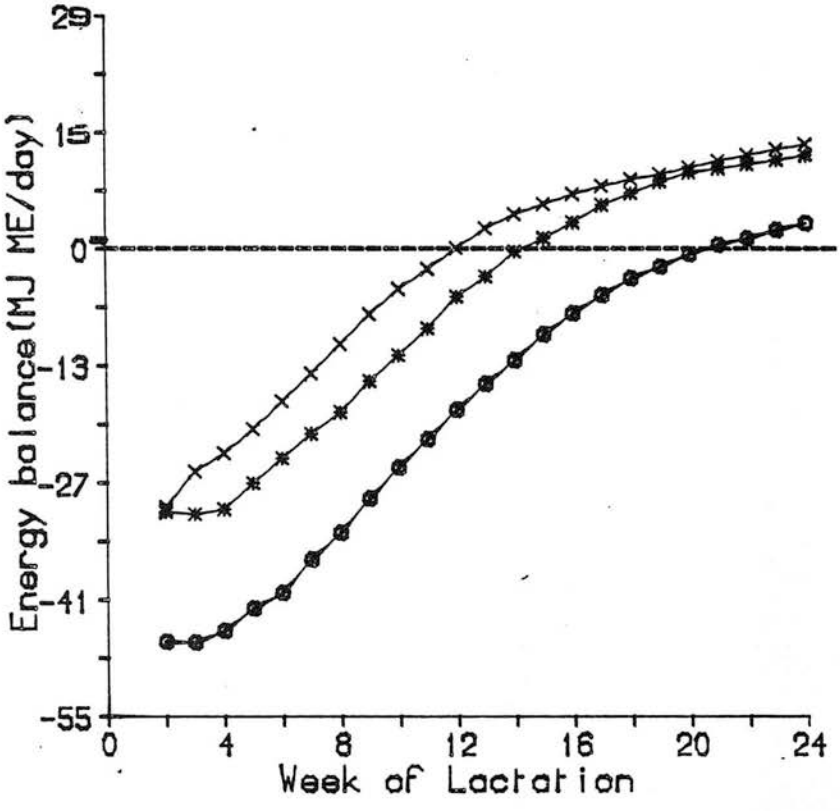
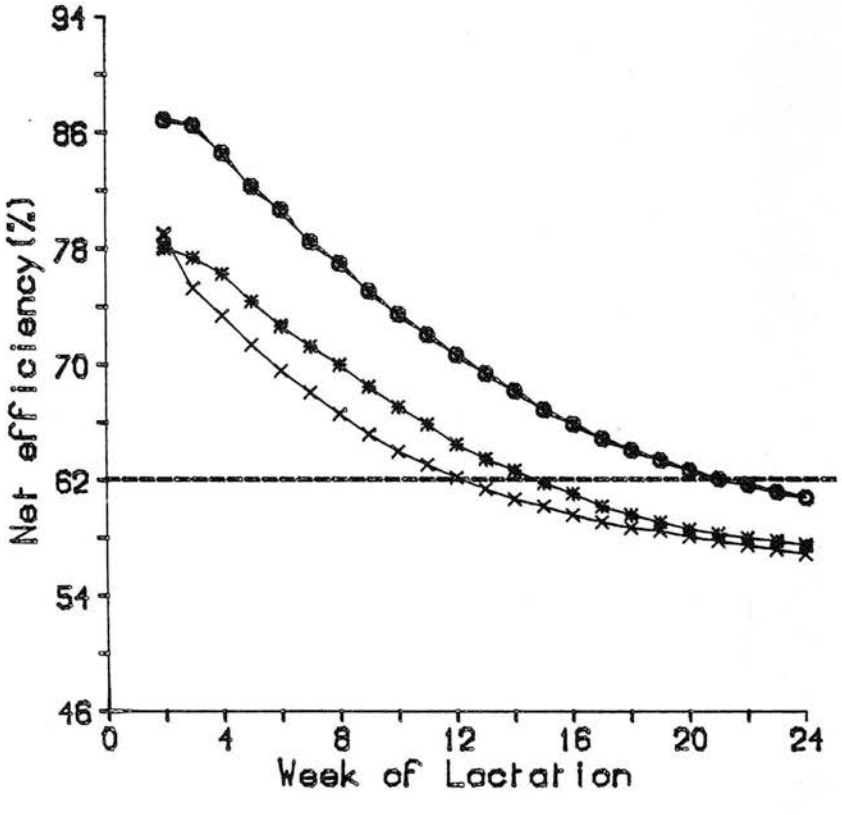


Figure 5.6 : Mean estimated net efficiencies(%) between weeks 2 and 24 of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).



most stages of lactation and energy balance in lactation stages 1 and 4 (Trial 1) and stage 2 (Trial 2). It was inversely ($P < 0.05$) related to gross and nitrogen efficiencies in lactation stage 1 for results of Trial 1 but all efficiency traits in lactation stage 2 for Trial 2. Thus, in Trial 1, daily ME intake and energy balance respectively increased by 0.14-0.17 and 0.07 MJ while gross and nitrogen efficiencies respectively declined by 0.025-0.031 and 0.024-0.027%. Similarly, in Trial 2, a 1 kg increase in calving liveweight was associated respectively with 0.12-0.17 and 0.12 MJ increase in ME intake and energy balance, but 0.031-0.043, 0.033-0.051 and 0.016-0.038% decline in gross, net and nitrogen efficiencies.

5.2 Discussion

5.2.1 GENERAL

The inability of the high yielding dairy cow to consume enough ME to meet requirements in early lactation even under ad libitum feeding is acknowledged (Flatt et al, 1969; Coppock et al, 1974; Johnson, 1983; Phipps et al, 1984b) and the reasons have been discussed (Bines, 1976 and 1979). The degree of energy deficit in early lactation and the lag between ME intake and ME required is dependent on ME concentration of the diet (Coppock et al, 1974; Phipps et al, 1984b), milk yield potential of the animal (Flatt et al, 1969), body condition at calving (Kunz et al, 1985) and probably amino acid supply (Orskov et al, 1977).

In line with these observations cows of Trial 1 of the current study mobilized 23.0 MJ ME/day between lactation weeks 2-6 (Table 5.1) which was 9% of their ME intake requirements. In Trial 2 consisting mainly

of heifers, the animals generally were able to meet their ME intake requirements even in early lactation (Table 5.2). By weeks 7-12, however, animals in both trials were, on average, in positive energy balance. ME intake, however, continued to increase even though ME requirements declined as lactation progressed reaching 14-20% above ME requirements by lactation weeks 19-24. It should be noted, however, that reproductive requirements are not accounted for in this study.

There are contrasting reports in the literature on the ability of the dairy cows to regulate intake to meet their physiological requirements. McCullough (1972) and Simms (1972) suggested that cows fed high energy complete diets were able to regulate intake to meet their physiological requirements. While Coppock et al (1974) and Phipps et al (1984b) observed that energy intake was not related closely to requirements after cows had reached positive energy balance. It would seem from the results of the present investigation and those of Coppock et al (1974) and Phipps et al (1984b) that given the opportunity many cows will consume more energy than they need to maintain a degree of condition most producers desire (but not the cows). It seems also that cows over-consume relative to our definition of their requirements, because they prefer to carry 100-150 kg more fat than is desirable.

It is also documented that high yielding dairy cows are capable of mobilizing protein in early lactation for milk production (Belyea et al, 1978; Botts et al, 1979; Oldham, 1984). In the present work, however, animals on average were estimated to be in positive essential amino acid-N (EAA) supply even in weeks 2-6. Possible uptake of EAA for gluconeogenesis was not taken into account (Armstrong, 1982). Also, calculations were based on the New Protein System for ruminants (ARC,

1984); limitations of this system are known (Waldo and Glenn, 1984).

The observation that energy and nitrogen efficiencies declined as lactation progressed agrees with previous reports (Jumah et al, 1965; Flatt et al, 1969; Custadio et al, 1983; Johnson, 1983; Phipps et al, 1984ab). This pattern of efficiency change is attributable to nutrient mobilization from tissues early in lactation and diversion of energy towards body tissue synthesis later in lactation (Flatt et al, 1969; Trigg and Parr, 1981). The large decline in net efficiency between stages 1 and 2 of lactation could be attributable to the depletion of body reserves between the two stages of lactation in Trial 1. Heifers with less reserves to mobilize in early lactation would be expected to result in less decline in net efficiency from lactation stage 1 to stage 2. The decline (net efficiency) was 14% in Trial 1 but only 7% in Trial 2.

It would therefore seem that an efficient cow, during lactation, is one which exhibits little body weight change. Furthermore, the storage and mobilization of reserves in early lactation is less efficient than the direct conversion of food to milk (Van Es and Van Der Honing, 1979).

The 51-56% net efficiency obtained in the present work and 48-56% observed by Johnson (1983) and Phipps et al (1984ab) indicate that the assumed efficiency of 62% or 59% with a safety margin included (MAFF, 1975) are too high for lactation weeks 2-24. These differences are probably due to improved quality of present day diets and level of intakes being achieved by cows (Phipps et al, 1984b). This agrees with evidence of reduced efficiency of ME utilization for production due to feeding level on metabolizability of the diet (ARC, 1980). Restricted feedings resulted in high efficiencies of 55-58% (Phipps et al, 1984a).

According to MAFF (1975), 5.3 MJ ME above maintenance is required per kg FCM. In the current study, this was 5.7-6.2 MJ over lactation weeks 2-24 but 4.6-5.5 MJ in lactation weeks 2-6 (Appendix Tables A.24). These results would tend to suggest that 5.3 MJ ME/kg FCM is only an average value. In early lactation cows are unable to consume enough ME to satisfy this requirement, but later in lactation they have higher ME intakes than that suggested by feeding standards currently accepted.

Normal commercial practice is to feed 0.40 kg concentrate per kg milk yield for average herds (Broster, 1974), but Wilson and Wood (1983) found that high yielding herds were fed 0.38 kg/kg milk yield. The assumption is that this will supply 5.3 MJ ME/kg milk yields as suggested by MAFF (1975) and maintenance requirement will be satisfied from forage. The range was 0.39-0.43 kg concentrate per kg milk yield over lactation weeks 2-24 of this investigation. This indicates that concentrate required per kg milk yield can be achieved within suggested commercial herd range by feeding 40-50% concentrate in mixed diets.

The results indicate that animals which rank high in energy and nitrogen efficiencies in early lactation due probably to mobilization of body energy and protein may not rank similarly in these traits later in lactation. This was because correlation coefficients between the same nutrient utilization trait in one stage of lactation and the next stage of lactation declined as the time between the stages increased. This would tend to support the idea (Chapter 4.2.2.2) of a change in feed partition, later in lactation, away from milk energy toward body gain for animals mobilizing large amounts of body energy in early lactation. This is in line with the results of Broster et al (1969, 1975) who demonstrated that heifers on low levels of feed (lactation weeks 1-9) switched to high levels

of feeding (lactation weeks 10-18) partition more food into body gain at the expense of milk yield than those given high levels of feeding for the whole period.

It is also interesting to note that under the present system of feeding net efficiency is not highly repeatable between consecutive lactations. This is probably a reflection of differences between consecutive lactations in uniformity of diets fed and condition of the animals at calving on ME intake and milk energy yield (Broster and Broster, 1984). One could also speculate that some high yielding cows are unable to recover from the stress of the previous lactation thus causing a decline in net efficiency in the succeeding lactation.

The present results demonstrated that 16-81% of the variation in energy and nitrogen utilization traits could not be explained by environmental and animal (immediately post-partum) factors. The three most important animal factors influencing these traits were liveweight change, milk yield in lactation week 2 and liveweight for Trial 1, but liveweight change, parity (probably because of the heifers) and milk yield in lactation week 2 for Trial 2. The total variation explained by these factors was generally higher in early lactation but declined as lactation progressed. The reason for the declining effect of these factors on these traits are similar to those provided for DMI (Chapter 3.2.1) and are therefore not repeated here.

5.2.2 EFFECTS OF VARIOUS FACTORS ON ENERGY AND NITROGEN UTILIZATION TRAITS

5.2.2.1 Environmental Effects

Differences between animals in energy and nitrogen utilization are

related to differences in milk energy yield, appetite and body tissue change (Blake and Custodio, 1984). Differences due to environmental factors (years and months of calving) could therefore be due to differences in any of these variables. Since the animals were housed climatic changes would play a very small role in these differences. Year differences in the present investigation in energy utilization traits were mostly due to differences in energy intake. FCM yield was not significantly different between years in most stages of lactation. Also, weight change was included in the model to account for differences in weight or tissue changes. The quality of weight change as an index of tissue change was discussed by Moe et al (1971).

One would normally not expect any differences in nutrient utilization between housed cows calving only 3 or 4 months apart. However, where the feeding management of concentrate in the diet is not constant but graded over periods of time, differences can occur. September calvers had significantly high ME consumption and were therefore higher in energy balance in stages 3 and 4 (Trial 1) than other monthly groups. Probably due to adjustments for differences in weight change, energetic efficiencies were not significantly different between months of calving. The large proportion of heifers in Trial 2 possibly accounted for lack of monthly differences in these traits. Milk production of heifers is less influenced by declining concentrate to forage ratios than cows (Ostergaard, 1979).

5.2.2.2 Effect of Parity

Under the control of homeorhetic mechanisms of body metabolism partition of nutrients between milk and body tissues should be influenced by parity (Bauman and Currie, 1980). Immature cows would be expected

to partition more food into growth than milk due to the drive to achieve mature size and the converse would be the case for mature cows. Immature cows would be expected to reach nutrient equilibrium earlier and be less gross efficient for milk production than mature cows. Furthermore, rate of attainment of nutrient equilibrium would increase with degree of immaturity.

After lactation weeks 2-6, only in Trial 2 were results of this experiment consistent with this expectation. In this trial, although ME intake significantly increased with increasing parity, older cows were still in negative energy balance in lactation weeks 2-8 (Figure 5.5). These results contradict estimates of Wood et al (1980) that heifers would be in negative energy balance until week 6.7 of lactation and Brown et al (1983) who showed that heifers have the ability to mobilize body energy for milk production and that differences between cows and heifers in energy balance was small. The greater lag between ME intake and ME required reported for heifers than cows (Bines et al, 1977) was not observed in this investigation.

Since energy balance is calculated by difference, cumulative errors from estimations of ME intake, milk energy and maintenance ME requirements and differences between experiments in composition of liveweight change were probably responsible for these differences. The use of complete diets in the present investigation, versus the feeding of concentrate and forage separately in the others, could explain some of these differences (Phipps et al, 1984a), caused by differences in VFI.

Adjustments of energy and nitrogen utilization traits for weight change was probably responsible for lack of significant differences between

parities in these traits for Trial 1. Miller and Hooven (1969) demonstrated increased gross efficiency with increasing parity. The current results are, however, consistent with the lower gross and nitrogen efficiencies of heifers than cows (Miller and Hooven, 1979; Wood et al, 1980; Cowan et al, 1981) and the similar net efficiencies of heifers and cows (Brown et al, 1983) observed by other workers and expected from the initial proposition.

5.2.2.3 Milk Yield (MY) x Calving Condition Score (CS) Interaction

The influence of calving condition on energy utilization traits in lactation weeks 2-6 depended on the daily milk yield of the cow in week 2 of lactation. This is consistent with an earlier report by Neilson et al (1983) of a significant intéraction of average daily milk yield in lactation weeks 1-26 and calving backfat area on gross efficiency (milk energy ÷ ME intake). These interactions were probably a reflection of the interaction between MY and CS on ME intake. There was no interaction between these factors on FCM yield (Chapter 4.12) or on milk energy yield ($P < 0.126$).

Possible reasons for the interaction with feed intake were given in Chapter 3.2.2.3. The interaction of MY x CS on energy balance tends to contradict the suggestion that animals preferentially utilized stored body fat rather than consume feed for milk production. Cumulative errors in estimation of energy balance and the few animals (16) in MY group 1 caution attachment of too much importance to this interaction. These results, however, tend to suggest that the driving force responsible for body energy mobilization in early lactation is neither milk yield potential of the animal nor calving condition score, but both acting

synergistically. Fat cows within each MY group had low ME intakes, high negative energy balances and high energetic efficiencies; this was more marked in low yielders. Furthermore, ME intake, negative energy balance and efficiency traits tended to increase with increasing milk yield for each CS group (Appendix Table A.37). Cows in the current experiment were generally in good condition (CS = 2.0-5.0, mean = 3.06, CV = 24.2%). It would be interesting to determine whether high yielding animals, thinner than those of this project, would similarly mobilize body energy during lactation. Cows calving between 1.5 and 2.0 condition score (mean = 1.75) were observed not to lose condition score during lactation (Garnsworthy and Topps, 1982b).

The fitting of a quadratic function to the relationships between CS and nutrient utilization variables failed to establish optimum calving body condition score. The question whether body tissue reserves are critical to the realisation of milk yield potential of high yielding cows (Bines and Hart, 1982) could not therefore be answered from these results.

5.2.2.4 Main Effect of Milk Yield

The present results are consistent with previous observations that high yielding cows have large appetites because of high nutrient requirements (Bryant, 1981; Trigg and Parr, 1981; Custodio et al, 1983; Davey et al, 1983) and yet are still more efficient than low yielders (Custodio et al, 1983). This high efficiency of high yielding cows is attributed to their ability to partition more food to milk rather than body gain (Custodio et al, 1983; Broster and Broster, 1984).

The current results also demonstrated that the high yielding cow has the ability to mobilize large amounts of body energy early in lactation for

milk energy production. This is well illustrated in Figure 5.3. Thus MY3 (high yielders) animals mobilize 45 MJ ME/day compared with less than 10 MJ ME/day for MY1 (low yielders) animals in lactation week 2. The physiological limit of this source of energy is not known. However, Flatt et al (1969) demonstrated that cow Lorna mobilized 42-84 MJ energy daily while producing between 34-45 kg FCM daily. Whereas Broster and Alderman (1977) showed that the cow Quatum and heifer 55 producing 36-42 kg FCM daily mobilized only 14-34 MJ energy daily. In the current investigation 4 cows (53, 84, 115 and 170) calving at condition score 2.50-4.25 produced 39-48 kg FCM daily between lactation weeks 2-6 and lost 101-115 MJ ME/day. At 5.3 MJ ME/kg FCM (MAFF, 1975) this, mobilized energy, was equivalent to 19.1-21.7 kg FCM, about 50% of the daily FCM produced. This mobilization of body energy appears to be an inherent ability of some cows. It is therefore doubtful, under ad libitum feeding of high energy diets, if milk yields higher than those given would have resulted in higher negative energy balances. For example, cow 37 calving at condition score 3.75 produced 47 kg FCM daily between lactation weeks 2-6 but mobilized only 27 MJ ME/day; equivalent to only 5.1 kg FCM yield.

Why some animals have this peculiar ability to mobilize large quantities of energy is not clear. It would appear, as previously discussed, that the synergistic effect of milk yield and condition score are responsible for some of these large differences.

The unexpected finding of a significant relationship of milk yield in lactation week 2 with gross and nitrogen efficiencies in all stages of lactation after adjustments, for Trial 2 but not Trial 1, was probably due to the size of liveweight change. Liveweight change in Trial 2, mainly

of heifers, would be expected to contain more water and less fat and thus less energy. This change may therefore not reflect the same tissue energy changes for all parities.

5.2.2.5 Main Effect of Calving Condition Score

There is good agreement in the literature that increasing CS depresses energy intake (Garnsworthy and Topps, 1982b; Neilson et al, 1983; Garnsworthy and Garner, 1985), but increases negative energy balance and condition score loss (Land and Leaver, 1980; Grainger et al, 1982; Boisclair et al, 1984) in early lactation. The results of the present investigation give support to these observations. These results further indicated that CS had significant influence on nutrient utilization traits between lactation weeks 2-12; this is the period most animals are in negative energy balance (Bines, 1979). This suggests that the lag between ME intake and ME required can be partially attributed to CS (see Kunz et al, 1985). Whether this effect is due to physical limitations of the gut (Bines, 1976) or metabolites released from adipose tissues (Forbes, 1980) or just a physiological drive in fat animals to utilize body fat early in lactation is not clear. The preferential use of body fat in some mammals such as the grey seal for milk production has been reported (Anonymous, 1983).

The gross efficiency values of 40.3, 41.0 and 45.7% observed over 2-24 weeks of lactation for thin, medium and fat condition cows at calving (Table 5.5) were similar to 34.7, 35.2 and 38.8% values reported by Garnsworthy and Topps (1982b) feeding similar diets, but higher in energy concentration (12 MJ ME/kg DM).

Also, the unadjusted means for the effect of CS groups (Trial 1) on net

efficiency, though not reflecting exactly the effect of this factor due to confounding effects of other factors, showed that in lactation week 2 CS3 animals had a surprisingly average net efficiency of 87% (Figure 5.6). This high value could be due to errors of calculation or measurement; partial efficiency of utilization of body fat for milk energy yield is estimated as 82% (Van Es and Van Der Honing, 1979). It has, however, been predicted that maximal efficiency will be about 87% when long chain fatty acids were 22% of ME intake (Kronfeld, 1982). Probably this was the case in the present investigation. Furthermore, due to lack of consensus, in the literature, on the effect of body fatness on maintenance requirements (Reid and Robb, 1971; Wright, 1982; Thomson et al, 1983) this was assumed to be similar for all CS groups. This could also have influenced these efficiency figures.

The significant difference between CS1 and CS3 animals in nitrogen efficiency (34.4 vs 28.1%, Table 5.7) in lactation weeks 2-6 was undoubtedly a reflection of the difference between the two groups in milk protein content (Chapter 4.1.2). These results suggest that either only a small amount of body protein was mobilized by fat animals for milk protein synthesis or that the protein mobilized was used for other purposes, for example gluconeogenesis (Armstrong, 1982) rather than milk N production. During early lactation more body energy than body protein is mobilized. The partition of this protein for gluconeogenesis and milk protein synthesis is not clear from the literature (Armstrong, 1982; Oldham, 1984). These results, however, indicate the importance of dietary nutrient supply for milk N synthesis.

5.2.2.6 Effect of Liveweight

For animals of similar condition score and milk yield but different

liveweight, the large animal would be expected to eat more due to its greater maintenance requirement and be less efficient in nutrient conversion to milk.

There is a consensus of opinion between this experiment and others reported that feed intake increases with increasing calving LW of the animal (Miller and Hooven, 1969; Miller et al, 1973; Hironaka et al, 1975; Korver, 1982). There is, however, lack of agreement on the influence of calving LW on energy utilization traits. Miller and Hooven (1969), Miller et al (1973) and Korver (1982) found significant inverse relationships between calving LW and energetic efficiency. Hironaka et al (1975) and Donker et al (1983) observed no significant influence of LW on energetic efficiency.

By contrast, in Trial 1 of the present investigation, calving LW had a significant inverse relationship with gross and nitrogen efficiencies in lactation stage 1 but was positively associated with energy balance in lactation stages 1 and 4. In Trial 2, on the other hand, calving LW resulted in significant increases in energy balance but significant declines in measures of efficiency in only lactation stage 2.

The confounding effects of condition score and/or gut fill on LW makes it impossible to explain differences between experiments in these relationships. Also, as pointed out by Blake and Custodio (1984), different measures of feed efficiency (FCM/net energy intake, milk energy/digestible energy, total digestible energy/FCM or milk energy/ME intake) may not be equally variable, which could lead to different biological interpretations.

5.2.2.7 Effect of Liveweight Change

In this work, liveweight change was expected to measure nutrient reserve

change while condition score measures the actual reserve. If this definition is right, liveweight change should be an important factor significantly influencing all measures of nutrient utilization. This was in fact the case in both trials of the present investigation. Liveweight change, even with all the inherent errors, proved to be the most important factor associated with most energy and nitrogen utilization traits. It was related to significant increases in ME intake and energy balance but significant decreases in nutrient efficiency. This was to be expected for it is only when milk energy requirements are satisfied that energy could be available for increased weight gain. Cows gaining weight would therefore tend to be less efficient because of partition of energy into gain rather than milk.

The relationship of weight change with energy utilization traits tended to be strongest in the first 12 weeks of lactation, at a time when most cows are expected to be mobilizing body reserves (Broster and Alderman, 1977; Bines, 1979). Also, the relationship between energy balance and weight change (regression coefficients) declined as lactation progressed for Trial 1. An indication of replacement of mobilized tissues by water or protein which have low energy values. This suggests that large differences exist during lactation in the amount of energy required to change body weight. The less variable regression coefficients in Trial 2 (mainly heifers) would tend to indicate that weight change which reflects growth is less variable in energy.

The interaction of stage of lactation and liveweight change on energy value of liveweight change is probably responsible for the variable energy values of liveweight change reported in the literature (see Broster and Broster, 1984). The present results therefore caution the use of an

average energy value of liveweight change as recommended by MAFF (1975) and ARC (1980).

The current results also demonstrated that weight change caused more variation in energetic efficiency than nitrogen efficiency (R^2(%) = 3.0-20.2 vs 0.4-10.6 (Trial 1) and 8.8-24.42 vs 3.3-17.9% (Trial 2)); suggesting that weight change measures body fat more accurately than protein. This agrees with reported results on body weight changes (Belyea et al, 1978; Wright, 1982).

The results of this investigation, however, differ from results of Grieve et al (1976) who observed negative correlations between feed intake and liveweight change and Miller and Hooven (1969) who found significant relationships between liveweight change and gross efficiency (FCM/estimated net energy) only between lactation days 181-210. They are, however, consistent with the results of Korver (1982). These differences are probably due to the definition of weight change. In these other reported experiments, weight change was computed as: ending of lactation liveweight minus starting of lactation liveweight. In this experiment, this was calculated as: current weekly liveweight minus preceding weekly liveweight. The present definition should correspond more accurately to changes in that stage of lactation than when weight change is considered over a wide range.

5.3 Conclusion

The results showed that ME intake increased at a slower rate than calculated ME requirements for cows (Trial 1) resulting in negative estimated energy balance (23.0 MJ ME/day) in lactation weeks 2-6. However, after this period,

in both trials, though energy requirements declined, energy intake increased to 115-120% of requirements in lactation weeks 19-24. Efficiency traits were high in early lactation, but declined steadily as lactation progressed.

Animal and environmental factors accounted for 49.2-69.0% of the total variation in energy balance, gross, net and nitrogen efficiencies in lactation weeks 2-6. The influence of these factors on these traits, however, declined as lactation progressed.

Calving condition score (CS) was significantly associated with low energy intake, energy balance and nitrogen efficiency but high gross and net efficiencies in lactation stages 1 and 2. The negative or positive effect of this factor on all these traits, except nitrogen efficiency, was less marked for animals with particularly high milk yields at this time.

Liveweight at calving was positively correlated with energy intake and energy balance, but was inversely related to efficiency traits.

Weekly weight change was the most important factor associated with the nutrient utilization traits in all stages of lactation. It was positively associated with ME intake and energy balance, but was negatively associated with all efficiency traits. The regression coefficients of liveweight change on these traits declined as lactation progressed, especially in cows.

Milk yield in lactation week 2 was positively correlated with ME intake and efficiency, but negatively with energy balance.

Cows had significantly higher ME intakes, but were still more efficient than heifers in utilization of energy and nitrogen for milk production. Repeatability of energy balance and net efficiency between 1st and 2nd lactations was low. Repeatabilities of nutrient utilization traits between different stages of

lactation declined as the time separating the stages increased.

In conclusion: under ad libitum feeding of 11.8 MJ ME/kg DM complete diet, body energy mobilization in lactation weeks 2-6 is inevitable for the high yielding cow. Selection of cows for high milk yields results in animals with high levels of feed intakes and efficiency; and also the ability to mobilize body reserves in early lactation. Milk yield potential and calving condition appear to have a synergistic effect on body energy mobilization. Experiments with cows over a range thinner than those in the current experiment are required to determine if it is milk yield potential or calving body fat which is responsible for the animals being in negative energy balance. Large but not fat cows have an advantage in ME intake and energy balance, but not efficiency in early lactation. Differences between cows in efficiency are due largely to differences in liveweight change. The energy value of liveweight change is variable across different stages of lactation. The use of an average energy value of liveweight change throughout lactation is therefore questioned. Environmental and animal (immediately post-partum) factors are surprisingly poor predictors of nutrient utilization traits.

6 LIVEWEIGHT, CONDITION SCORE, BACKFAT AREA AND THEIR CHANGES

6.1 Results - Trial 1

6.1.1 GENERAL

Post-calving LW and BS declined as lactation progressed, reaching minimum values in lactation stage 2 (weeks 7-12). However, post-calving BFA reached minimum values in lactation week 12 (Table 6.1). Thus, on average, animals lost 11 kg LW and 0.11 units BS between calving and lactation stage 1 (weeks 2-6), but had gained 11 kg LW by lactation stage 4 (weeks 19-24). This was reflected in a weekly LWC of -2.5 kg in lactation stage 1 and +1.1 kg in lactation stage 4.

The animals had, however, not regained post-calving BS loss by lactation stage 4, suggesting differences between the two live measurements (LW and BS). This is further reflected in the linear and quadratic coefficients of LW and BS curves (Appendix Table A.40). The average coefficients of weekly LW and BS were 1.229 (linear) and 0.690 (quadratic); -0.0497 (linear) and 0.002 (quadratic) respectively. These coefficients indicate no LW loss during the 24 week experimental period.

An attempt was made to estimate body tissue fat, protein and energy changes using the following equations derived from live body measurements and body composition of slaughtered cows:

1. Empty body weight (EBW) kg = LW - 5.50 daily dry matter intake

   (derived from data of Hartnell and Saffer, 1979 and G C Emmans

- Personal Communications).

2. Body fat (BF) kg = -201.2 + 6.32 BFA - 0.584 EBW

(from equation 21, Appendix Chapter 3, Table A.3.3).

3. Body protein (BP) kg = -24.6 ± 11.4 + 0.3772 ± 0.0390 REST

(R^2 = 88.5%; RSD = 3.20)

4. Body energy (BE) MJ = 39.3 BF - 23.7 BP

Where Rest = EBW - BF

Estimated BF, BF and BE changes between lactation weeks 1-6 were -841.0 and -3.6 g/day and -33.1 MJ/day respectively. The high standard deviations reflect the variability of these estimates (Appendix Table A.40).

6.1.2 EFFECTS OF DIFFERENT FACTORS ON LIVE BODY MEASUREMENTS

The effects of year of calving, month of calving, parity, daily milk yield in lactation week 2 (MY), calving condition score (CS), MY x CS, weekly liveweight change in the corresponding stage of lactation and calving liveweight on live body measurements were tested by analysis of variance. The live body measurements were either analysed using Model 1, containing all factors, or a shortened version excluding calving liveweight or calving condition score. The exclusion of calving liveweight in the analysis of LW and calving condition score in the analysis of BS was an attempt to prevent bias. The corresponding least squares means for LW, LWC, BS, condition score change (BSC), BFA and backfat area change (BFAC), from the analysis are provided in Tables 6.2-6.5 and Appendix Tables A.41-A.46.

Months of calving had some surprising effects on LWC, BSC and BFAC.

Table 6.1 Means, standard deviations (SD) and residual standard deviations (RSD) of liveweight, condition score and other traits per stage of lactation - TRIAL 1

TRAIT	Mean	SD	RSD	R^2(%)*
Liveweight (kg)				
At calving	645	67.5	-	-
Stage 1	634	59.8	38.2	61.0
2	633	57.3	43.4	50.8
3	646	59.1	46.9	45.6
4	655	58.7	47.1	47.9
1-4	643	56.6	40.7	54.6
Weight change (kg/week)				
Stage 1	-2.5	6.1	5.5	31.5
2	1.2	3.8	3.3	36.1
3	2.1	3.1	2.9	22.2
4	1.1	3.1	3.0	19.1
1-4	0.6	2.3	1.4	47.3
Condition score (1-5 units)				
At calving	3.06	0.74	-	-
Stage 1	2.95	0.66	0.37	65.2
2	2.78	0.58	0.37	59.2
3	2.85	0.62	0.45	51.3
4	2.98	0.59	0.44	47.6
1-4	2.89	0.58	0.35	58.4
Condition score change				
Weeks 1-6	-0.26	0.44	0.38	38.4
1-12	-0.10	0.53	0.46	45.6
1-18	-0.03	0.51	0.40	43.3
Backfat area (cm^2)				
At calving	6.87	2.04	-	-
Week 6	5.10	1.48	1.18	45.0
12	4.93	1.34	1.06	47.7
18	5.71	1.41	1.13	42.9

* Per cent of variation explained by Model 1

Table 6.2 Least squares means and standard errors (SE) and estimates of the effects of liveweight change - kg/week (regression coefficients (b)) for average liveweight (kg) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	635.3	6.78	633.1	7.28	647.5	8.09	659.1	8.12	641.5	6.93
Parity											
2	26	587.4^{a}	11.12	592.6^{a}	11.80	602.7^{a}	13.35	633.9^{a}	13.36	593.1^{a}	11.49
3	34	637.9^{b}	9.01	636.3^{b}	9.74	657.9^{b}	10.71	670.9^{b}	10.78	645.9^{b}	9.48
4	25	646.2^{b}	9.42	641.0^{b}	10.12	657.7^{b}	11.26	666.1^{b}	11.30	652.4^{b}	9.59
5	30	669.7^{c}	8.80	662.7^{c}	9.41	671.7^{b}	10.50	675.6^{b}	10.48	674.5^{c}	9.03
Condition score groups											
1	65	602.1^{a}	7.00	606.4^{a}	7.56	626.2^{a}	8.24	634.6^{a}	8.29	613.5^{a}	7.18
2	26	644.3^{b}	8.96	645.7^{b}	9.67	663.3^{b}	10.66	672.1^{b}	10.74	652.8^{b}	9.19
3	24	659.5^{c}	16.05	647.4^{b}	17.30	653.0^{b}	19.21	670.6^{b}	19.20	658.1^{b}	16.33
Weight change (b,SE)	115	1.408	0.6844*	4.532	1.222**	1.984	1.548	0.7771	1.487	8.604	2.083**

^{abcd} Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

Table 6.3 Least squares means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - lactation weeks 2-6 (kg/week) (regression coefficients (b)) for weight change (kg/week) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	-1.63	0.911	1.46	0.563	2.43	0.501	1.44	0.512	0.97	0.304
Parity											
2	26	-1.53	1.569	1.39	0.970	3.28	0.863	2.74	0.881	1.38	0.524
3	34	-0.93	1.212	2.41	0.749	2.32	0.666	1.55	0.681	1.43	0.405
4	25	-1.62	1.299	1.30	0.803	2.77	0.714	0.55	0.730	0.86	0.434
5	30	-2.45	1.287	0.75	0.796	1.34	0.708	0.92	0.723	0.22	0.430
Condition score groups											
1	65	-2.12	1.067	2.40	0.659	1.61	0.586	1.78	0.599	1.01	0.356
2	26	-1.17	1.181	2.08	0.730	2.36	0.649	1.66	0.664	1.23	0.394
3	24	-1.61	2.253	-0.09	1.393	3.31	1.239	0.88	1.257	0.67	0.752
Weight change (b,SE)	115			0.1614	0.0905	-0.0955	0.0841	-0.1200	0.0875	0.2149	0.0371*
Calving liveweight (b,SE)	115	-0.0310	0.0123*	0.0005	0.0076	-0.0058	0.0068	0.0030	0.0069	-0.0088	0.0041

* $P < 0.05$

Table 6.4 Least squares means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) for average condition score (1-5 units) per stage of lactation - TRIAL 1

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	3.00	0.054	3.02	0.054	2.91	0.059	3.04	0.059	2.91	0.045
Parity											
2	26	3.08	0.108	3.10	0.109	2.88	0.121	3.05	0.119	2.92	0.090
3	34	3.03	0.081	3.07	0.084	3.07	0.089	3.20	0.089	2.97	0.068
4	25	2.86	0.086	2.88	0.087	2.82	0.095	2.93	0.094	2.80	0.071
5	30	3.03	0.085	3.03	0.086	2.88	0.095	2.98	0.093	2.94	0.070
Weight change (b,SE)	115	0.0129	0.0071	-0.0153	0.0115	0.0205	0.0141	0.0023	0.0137	0.0105	0.0018**
Calving liveweight (b,SE)	115	0.0068	0.00008	0.0062	0.00076	0.0038	0.00083	0.0036	0.00082	0.0057	0.00064

** $P < 0.01$

Table 6.5 Least squares means and standard errors (SE) and estimates of calving liveweight (kg) and liveweight change - kg/week (regression coefficients (b)) for condition score change between calving and different weeks of lactation - TRIAL 1

WEEKS OF LACTATION		1-6		1-12		1-18	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
All	115	0.29	0.063	0.15	0.073	0.11	0.070
Parity							
2	26	-0.24	0.107	-0.07	0.123	-0.08	0.119
3	34	-0.25	0.087	-0.02	0.102	0.04	0.096
4	25	-0.36	0.091	-0.29	0.105	-0.22	0.102
5	30	-0.31	0.086	-0.21	0.099	-0.19	0.096
Condition score groups							
1	65	-0.15	0.084	-0.09	0.081	0.10[a]	0.078
2	26	-0.21	0.080	-0.08	0.097	-0.02[a]	0.093
3	24	-0.51	0.151	-0.28	0.174	-0.42[b]	0.168
Weight change (b,SE)	115	0.0124	0.0069	0.0289	0.0080**	0.0237	0.0077**
Calving liveweight (b,SE)	115	-0.00031	0.00044	0.00021	0.00050	0.00014	0.00049

** $P < 0.01$

Thus, although September calvers had a significantly ($P < 0.05$) greater LW gain in lactation stages 3 and 4, they also had significantly greater BS loss (lactation stages 1-6 and 1-12) and BFA loss (lactation stages 1-12) but were still slightly heavier than other monthly groups (Appendix Tables A.41-A.46). This is a further suggestion that LWC, BSC or BFAC do not measure the same tissue change.

As would be expected, LW ($P < 0.01$), BS and BFA ($P < 0.05$) increased with increasing age of the cow. However, although LW, BFA and BS gain tended to decline with increasing parity, this was not statistically significant at any stage of lactation.

Increased daily milk yield in lactation week 2 was associated with increased LW, BS and BFA loss, but this was only significant ($P < 0.05$) in BFA loss (lactation weeks 1-18). These losses were, however, reflected in the significant ($P < 0.05$) lower BS of MY_3 animals (see Chapter 2.8 for groupings) in most stages of lactation compared to other milk yield groups. The trends in unadjusted means for LW, BS, BFA and LWC over 24 weeks of lactation are illustrated in Figures 6.1-6.4. MY_3 animals had the greatest decline in LW, BS and BFA resulting in lower values of BS and BFA in latter parts of the experimental period than other milk yield groups. All milk yield groups, however, lost, on average, 0.5-1 kg/day of LW between lactation weeks 2-10 (Figure 6.4).

Grouping animals into 3 CS groups (Chapter 2.8) naturally resulted in the heaviest animals being the fattest and thin animals being the lightest (Table 6.2). A unit increase in calving condition score was associated with 63-177 kg (average 105 kg) increase in calving LW for cows, but averaged 149 kg for cows and heifers (Appendix Table A.49

equations 18-22). Regression coefficients were found to be parallel and not significantly different for cows and heifers and were thus pooled. High calving condition score or BFA values were associated with greater BS and BFA loss but with still higher values of BS and BFA during lactation (Table 6.5; Appendix Tables A.45, A.49 and Figure 6.12). Thus CS_3 animals lost ($P < 0.05$) the most BFA and BS in lactation weeks 1-18 but were still significantly heavier in all stages of lactation (Table 6.3) and had significantly ($P < 0.01$) the highest BFA in lactation weeks 1, 6 and 12 (Appendix Table A.45).

Trends of the unadjusted means for LW, BS and BFA change and LWC during the experiment are provided in Figures 6.5-6.8. CS_3 animals declined most in LW, BS and BFA and reached minimum values of these traits later than other CS groups. By lactation week 24 these same animals had not recovered post-calving LW, BS and BFA loss.

Estimated body fat, energy and protein (Appendix Table A.48) indicated that in lactation weeks 1-6 all CS groups lost body fat and energy but only CS_3 animals lost body protein (3.6 g/day).

Weekly LWC was surprisingly only positively associated ($P < 0.05$) with LW in lactation stages 1 and 2, BS in lactation stage 1-4 and BFA in lactation week 12 instead of all lactation stages as would be expected. However, LWC (lactation stage 1) was positively correlated ($P < 0.05$) with BSC in lactation weeks 1-12 and 1-18, BFAC in lactation weeks 1-12, but with only LWC over lactation stage 1-4, indicating that LWC in early lactation had no effect on LWC later in lactation (Table 6.3).

Calving LW was, as expected, positively associated with BS in all lactation stages. The inverse relationship ($P < 0.05$) between calving LW and LWC in lactation stage 1 was, however, unexpected. Thus a

Figure 6.1 : Mean live weights(kg) during 24 weeks of lactation for 3 milk yield groups :MY1(low,X),MY2(medium,*),MY3(high,o).

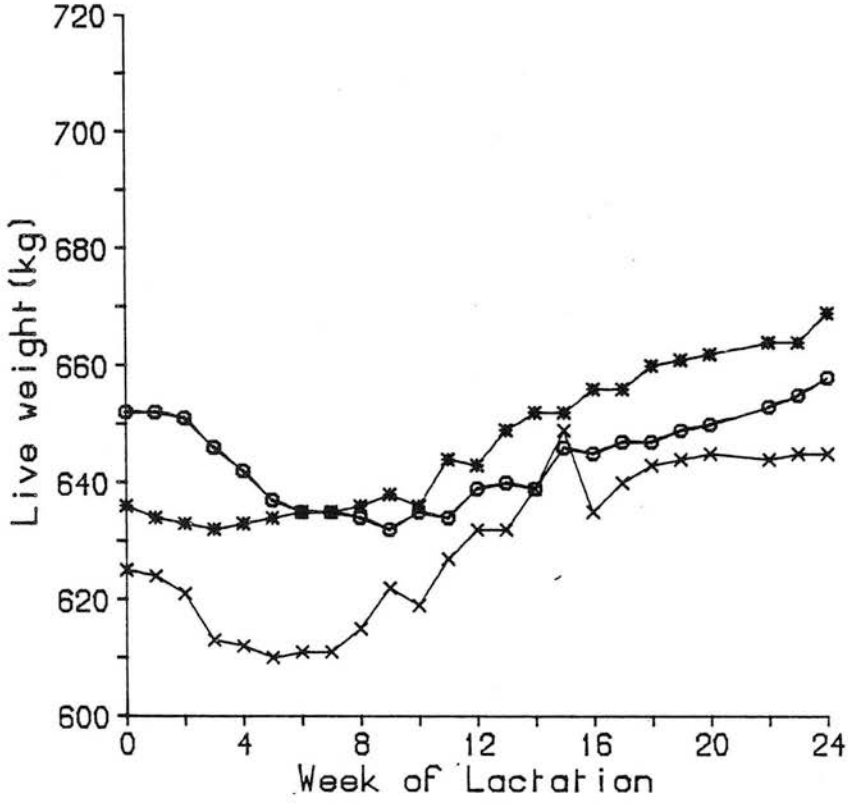


Figure 6.2 : Mean condition scores(1-5 units) during 24 weeks of lactation for 3 milk yield groups :MY1(low,X),MY2(medium,*),MY3(high,o).

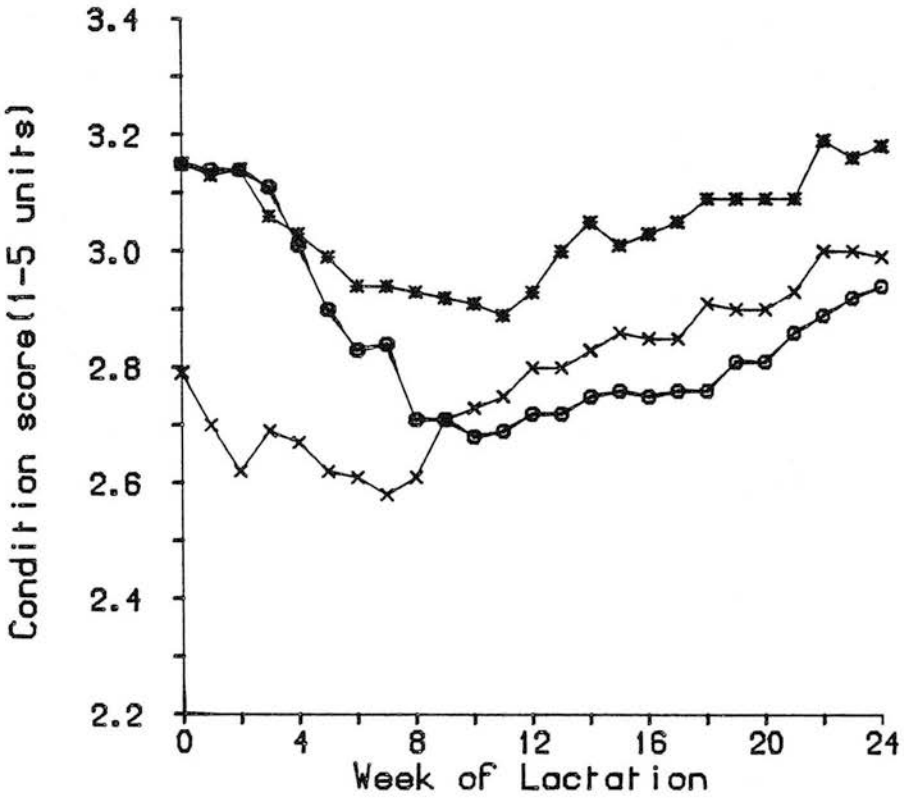


Figure 6.3 : Mean back fat areas(cm^2) during 18 weeks of lactation for 3 milk yield groups :MY1(low,X),MY2(medium,*),MY3(high,o).

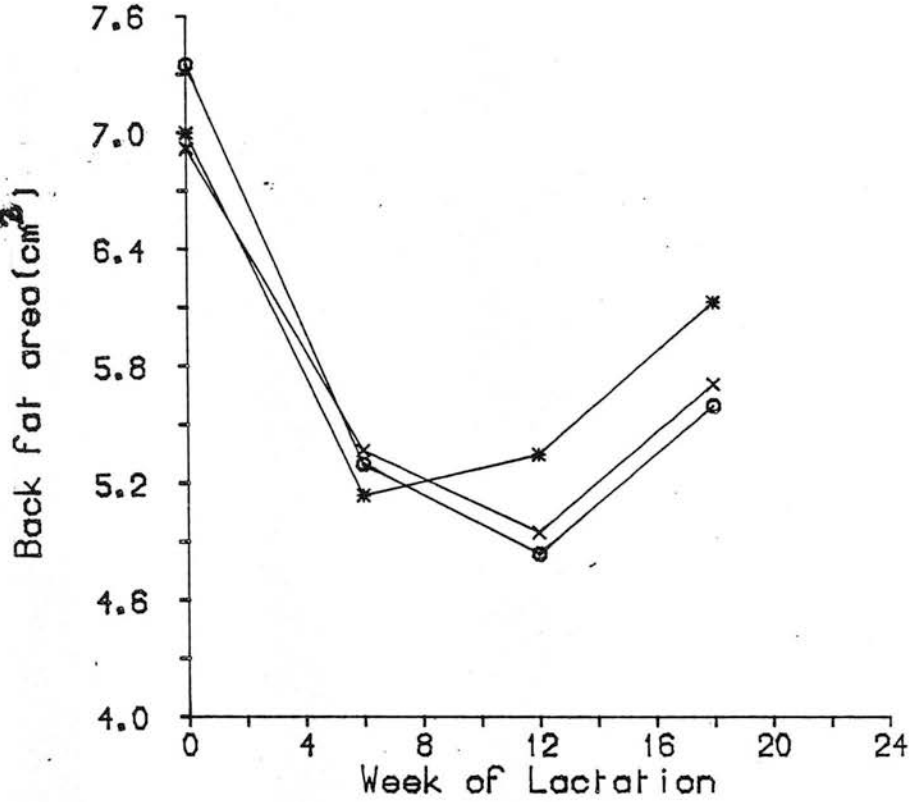


Figure 6.4 : Mean live weight changes(kg/week) between weeks 2 and 24 of lactation for 3 milk yield groups:MY1(low,X),MY2(medium,*),MY3(high,o).

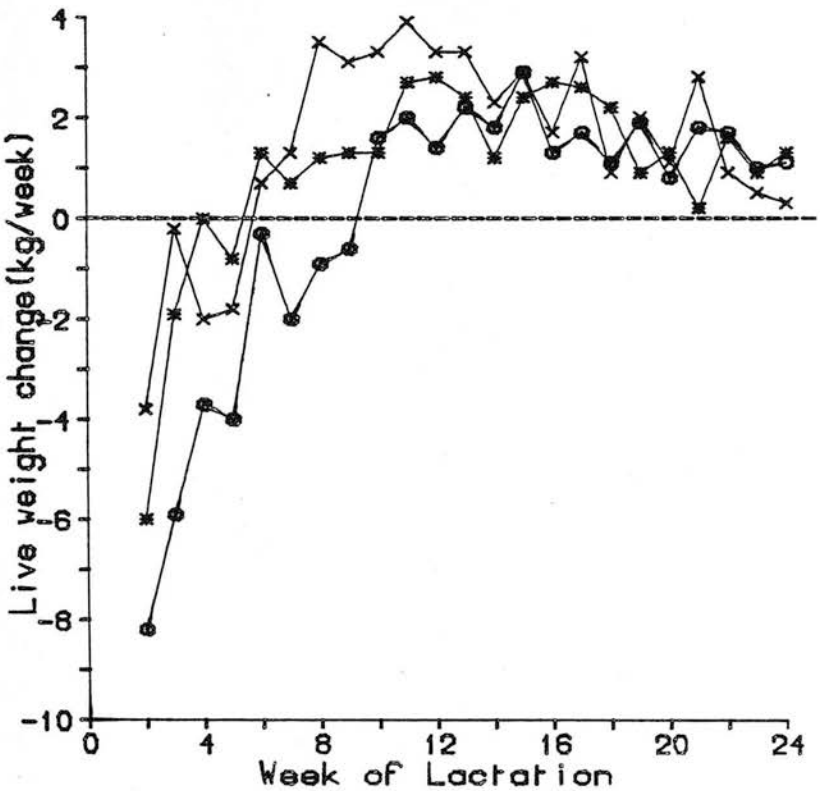


Figure 6.5 : Mean live weights(kg) during 24 weeks of lactation for 3 condition score groups :CS1(thin,X),CS2(medium,*),CS3(fat,o).

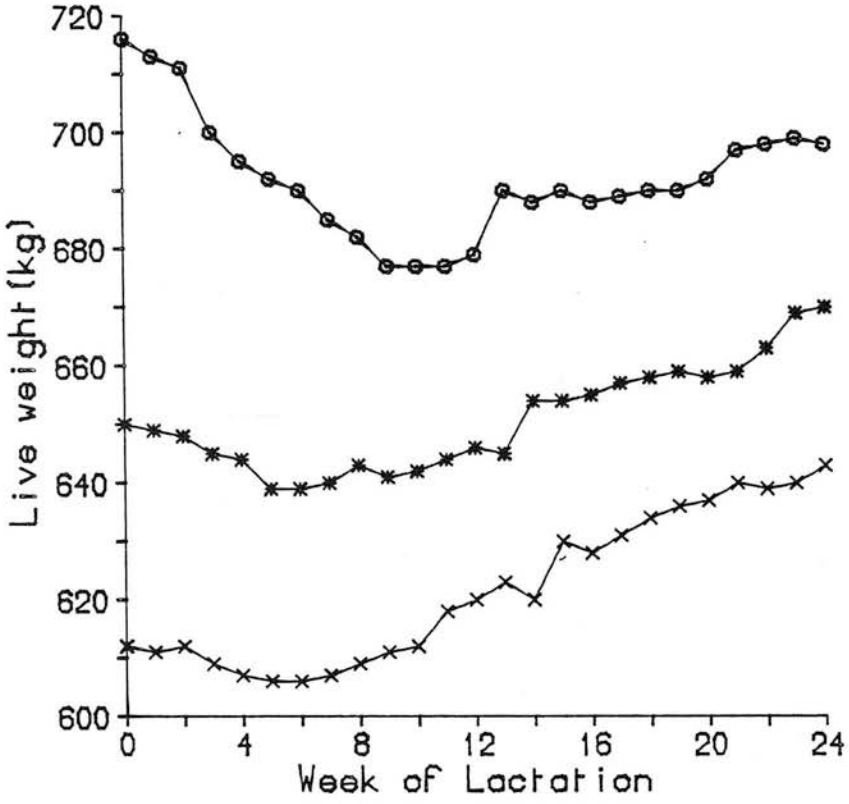


Figure 6.6 : Mean condition scores(1-5 units) during 24 weeks of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).

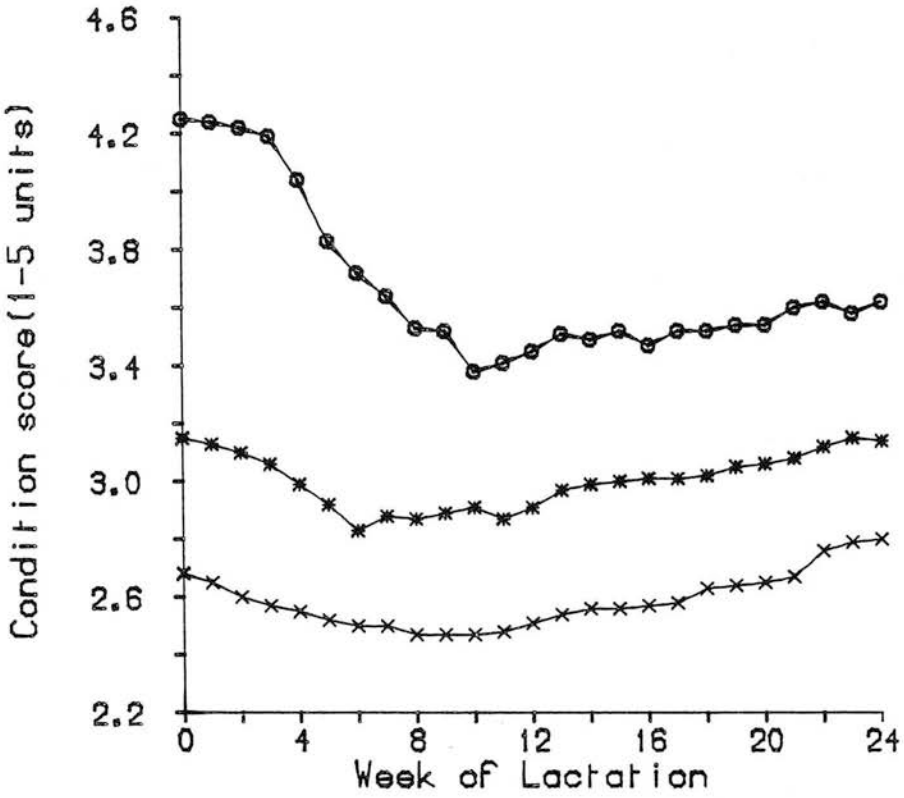


Figure 6.7 : Mean back fat areas(cm^2) during 18 weeks of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).

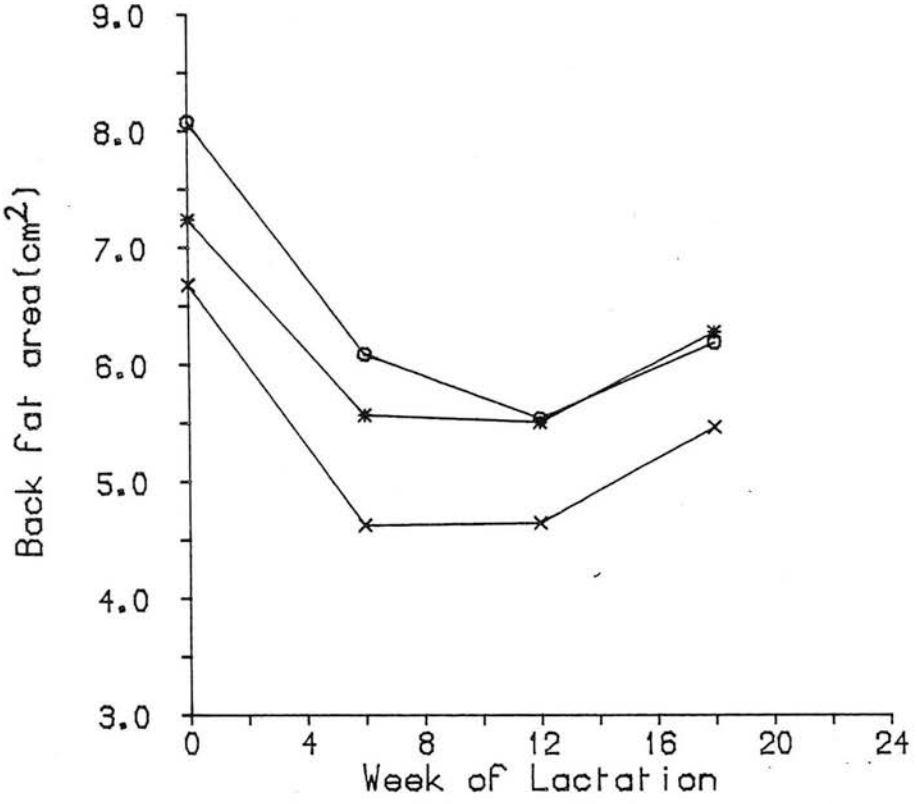
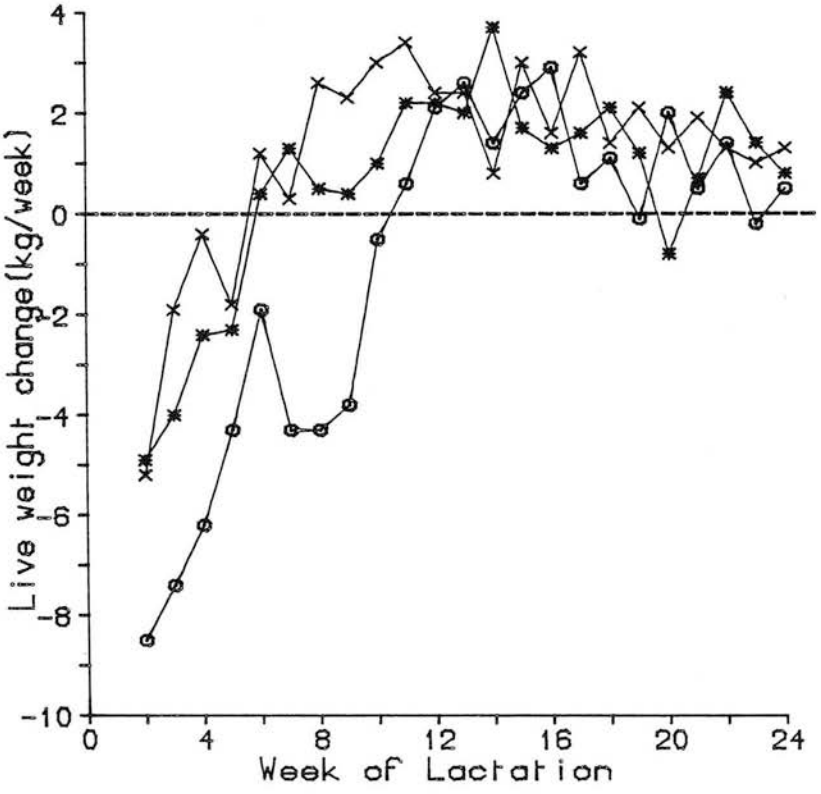


Figure 6.8 : Mean live weight changes(kg/week) between weeks 2 and 24 of lactation for 3 condition score groups:CS1(thin,X),CS2(medium,*),CS3(fat,o).



1 kg increase in calving LW was equivalent to 0.03 kg/week liveweight loss at this time (Table 6.3).

6.2 Results - Trial 2

6.2.1 GENERAL

The mean LW, LWC and BS are shown in Table 6.6. Mean post-calving LW was 566 kg and mean post-calving BS 2.77 units. Both LW and BS declined as lactation progressed, reaching minimum values in lactation stage 1 (weeks 2-6) and stage 2 (weeks 7-12) respectively. By lactation stage 2, on average, animals had regained their post-calving LW. However, by lactation stage 4 (weeks 19-24) these animals had not regained their post-calving BS. These changes were reflected in a weekly weight change of -0.44 kg in lactation stage 1 but +2.80 kg in lactation stage 4.

6.2.2 EFFECTS OF DIFFERENT FACTORS ON LIVE BODY MEASUREMENTS

The associated least square means and unadjusted parity group means of LW, LWC, BS from the results of analysis of variance on these traits by Model 2 or a shortened form of this model are provided in Tables 6.7-6.9 and Appendix Tables A.50-A.52.

Month of calving had no significant effect on average LW in any stage of lactation even though September and October calvers had higher ($P < 0.01$) liveweight gains than November-December calvers in lactation stage 4 (Appendix Table A.51). However, November-December calvers decreased most in BS resulting in lower values ($P < 0.05$) in lactation stage 2 for this group (Appendix

Table 6.6 Means, standard deviations (SD), residual standard deviations (RSD) of liveweight, condition score and liveweight change per stage of lactation - TRIAL 2

TRAIT	Mean	SD	RSD	R^2%*
Liveweight (kg)				
At calving	566	63.0	-	-
Stage 1	562	60.2	36.0	67.7
2	572	60.1	37.6	64.7
3	590	61.3	39.3	63.2
4	607	62.8	41.0	62.8
1-4	583	59.7	35.1	69.0
Liveweight change (kg/week)				
Stage 1	-0.44	4.04	3.33	39.4
2	2.79	2.27	2.22	15.5
3	3.16	2.09	2.07	13.3
4	2.80	1.79	1.69	21.8
1-4	2.10	1.46	1.10	49.8
Condition score (1-5 units)				
At calving	2.77	0.29	-	-
Stage 1	2.71	0.30	0.19	63.5
2	2.57	0.29	0.20	55.8
3	2.57	0.30	0.25	39.4
4	2.65	0.32	0.26	39.0
1-4	2.62	0.28	0.19	60.0

* Per cent of variation in trait explained by Model 2

Table 6.7 Unadjusted parity groups means and standard errors (SE) and estimates of the effects of calving condition score and liveweight change - kg/week (regression coefficients (b)) for average liveweight (kg) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	0.4401	1.1254	2.362	1.972	2.964	2.245	3.989	2.128	9.927	3.217
Calving condition score (b,SE)	75	11.77	1.542**	10.49	1.559**	10.88	1.644**	5.814	1.781**	11.526	1.477**
Parity groups											
1a	24	523.1^{a}	9.71	535.4^{a}	9.63	554.3^{a}	10.00	570.8^{a}	10.31	546.3^{a}	9.63
1b	25	530.6^{a}	9.53	538.3^{a}	9.55	554.4^{a}	9.82	573.2^{a}	10.41	549.2^{a}	9.40
2	14	574.4^{b}	12.92	581.2^{b}	12.90	599.9^{b}	13.12	616.0^{b}	13.83	592.9^{b}	12.82
3	12	621.7^{c}	13.81	634.4^{c}	13.44	651.6^{c}	13.83	670.3^{c}	14.35	644.5^{c}	13.25
All	75	562.4	5.81	572.3	5.90	590.0	5.94	607.3	6.11	583.2	5.73
Level of significance		**		**		**		**		**	

^{abcd} Different superscripts in column indicate significant difference $P < 0.05$ ** = $P < 0.01$

Table 6.8 Unadjusted parity groups means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and condition score and liveweight change - lactation weeks 2-6 (kg/week) (regression coefficients (b)) for liveweight change (kg/week) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-	-	0.1246	0.0803	-0.1381	0.0749	-0.1302	0.0610*	0.2033	0.0398**
Calving liveweight (b,SE)	75	-0.0242	0.0109*	-0.0106	0.0074	-0.0045	0.0069	0.0059	0.0057	-0.0025	0.0037
Calving condition score (b,SE)	75	-0.228	1.915	-1.826	1.291	-0.972	1.204	-0.607	0.981	-0.146	0.641
Parity groups											
1a	24	0.09[a]	0.813	3.23	0.459	3.09	0.415	2.57	0.364	2.34	0.292
1b	25	-1.03[b]	0.797	2.54	0.450	2.53	0.407	3.01	0.357	1.74	0.285
2	14	-1.22[b]	1.086	2.70	0.613	3.03	0.554	2.79	0.486	1.78	0.390
3	12	0.42[a]	1.128	2.69	0.634	3.99	0.575	2.82	0.505	2.46	0.404
All	75	-0.44	0.484	2.79	0.273	3.16	0.247	2.80	0.217	2.10	0.174
Level of significance		*		NS		NS		NS		NS	

abcd Different superscripts in column indicate significant difference $P < 0.05$, * $P < 0.05$, ** $P < 0.01$

NS = Not significant

Table 6.9 Unadjusted parity groups means and standard errors (SE) and estimates of the effects of calving liveweight (kg) and liveweight change - kg/week) (regression coefficients (b)) for average condition score (1-5 units) per stage of lactation - TRIAL 2

STAGE OF LACTATION		1		2		3		4		1-4	
WEEKS OF LACTATION		2-6		7-12		13-18		19-24		2-24	
Factors	**Number of records**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Weight change (b,SE)	75	-0.00002	0.00689	0.0161	0.0107	-0.0781	0.1399	-0.0094	0.0182	0.0566	0.0011**
Calving liveweight (b,SE)	75	0.00421	0.00047*	0.00379	0.00047*	0.00316	0.00057*	0.00358	0.00062*	0.00420	0.00044*
Parity groups											
1a	24	2.79	0.058	2.63	0.057	2.63	0.061	2.62	0.065	2.62	0.056
1b	25	2.69	0.057	2.59	0.056	2.59	0.059	2.67	0.063	2.53	0.055
2	14	2.56	0.078	2.44	0.076	2.53	0.081	2.62	0.086	2.67	0.074
3	12	2.80	0.081	2.61	0.079	2.54	0.084	2.69	0.087	2.66	0.077
All	75	2.71	0.035	2.57	0.034	2.57	0.036	2.65	0.039	2.62	0.033
Level of significance		NS		NS		NS		NS		NS	

* $P < 0.05$, ** $P < 0.01$, NS = Not significant

Table A.52).

The unadjusted LW, BS and LWC changes with time for each parity group are illustrated in Figures 6.9-6.11. As was expected, LW, though not BS, increased ($P < 0.01$) with increasing parity (Tables 6.7 and 6.9). However, parity 2 animals had the lowest post-calving BS. This was caused by the inability of heifers to regain BS lost during lactation before the onset of the next lactation. This is borne out by the 8% higher calving condition score values of the same animal as a heifer than as a 2nd calver (Appendix Table A.47).

The pattern of LW and BS change over time was similar between parity groups, declining to minimum values by lactation weeks 6 and 12 respectively. However, parity 2 animals decreased most in BS, though by lactation week 20 post-calving BS lost had been regained. Also, animals in all parities lost LW between calving and lactation weeks 6-10. Year 5 heifers and 2nd parity cows, however, had a significantly ($P < 0.05$) higher LW loss in lactation stage 1 than other parity groups (Table 6.8 and Figure 6.11).

As would be expected, daily milk yield in lactation week 2 was negatively associated with BS, BSC and LWC in almost all stages of lactation. This relationship reached statistical significance ($P < 0.05$) for LWC (lactation stage 1) and for BS in all stages of lactation. Thus LWC declined by 0.38 kg/week whereas BS declined by 0.02-0.04 units per kg increase in daily milk yield (Appendix Tables A.51 and A.52).

As would be expected, a unit increase in calving condition score was equivalent to a significant ($P < 0.05$) increase in LW by 5.8-11.8 kg, but a non-significant decline of 0.2-1.8 kg/week for LWC. The significant

Figure 6.9 : Mean live weights(kg) during 24 weeks of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.),Second calvers(o),YR4Heifers(+),YR5 Heifers(x).

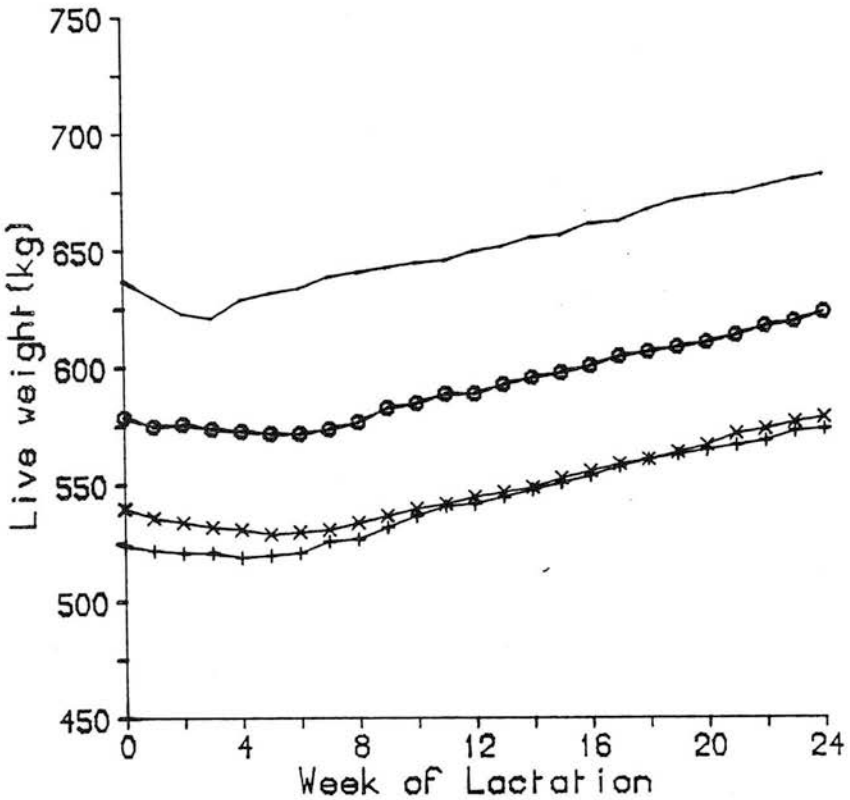


Figure 6.10 : Mean condition scores(1-5 units) during 24 weeks of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.),Second calvers(o),YR4 Heifers(+),YR5 Heifers(x).

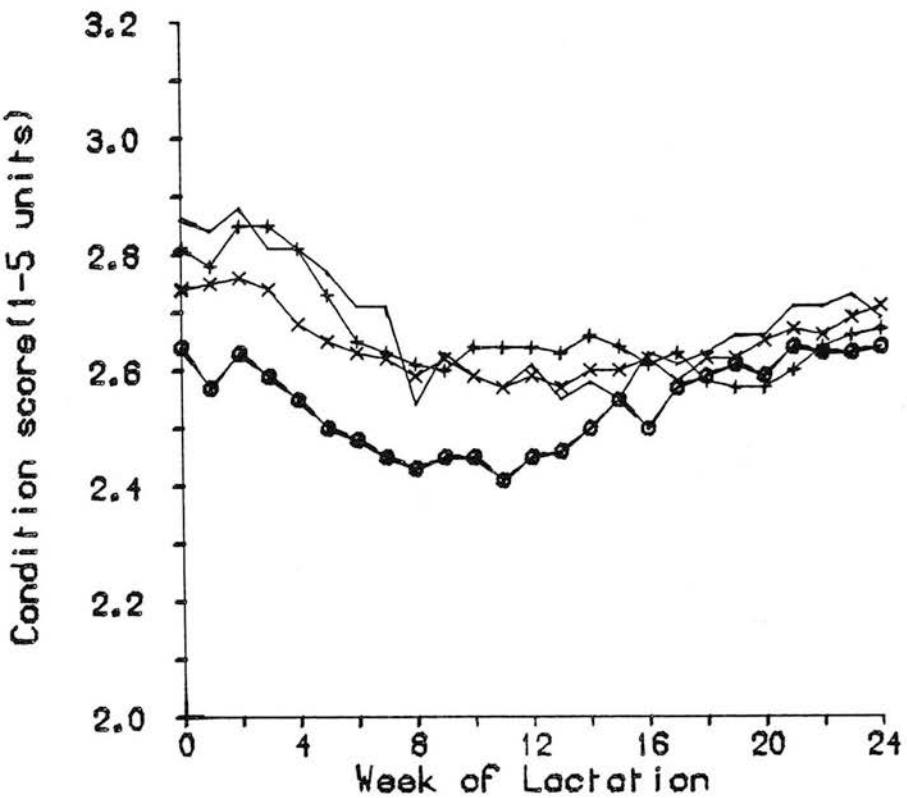


Figure 6.11 : Mean live weight changes(kg/week) between weeks 2 and 24 of lactation for cows and heifers of year(YR) 4 and year 5:Adult Cows(.), Second calvers(O),YR4 Heifers(+),YR5 Heifers(x).

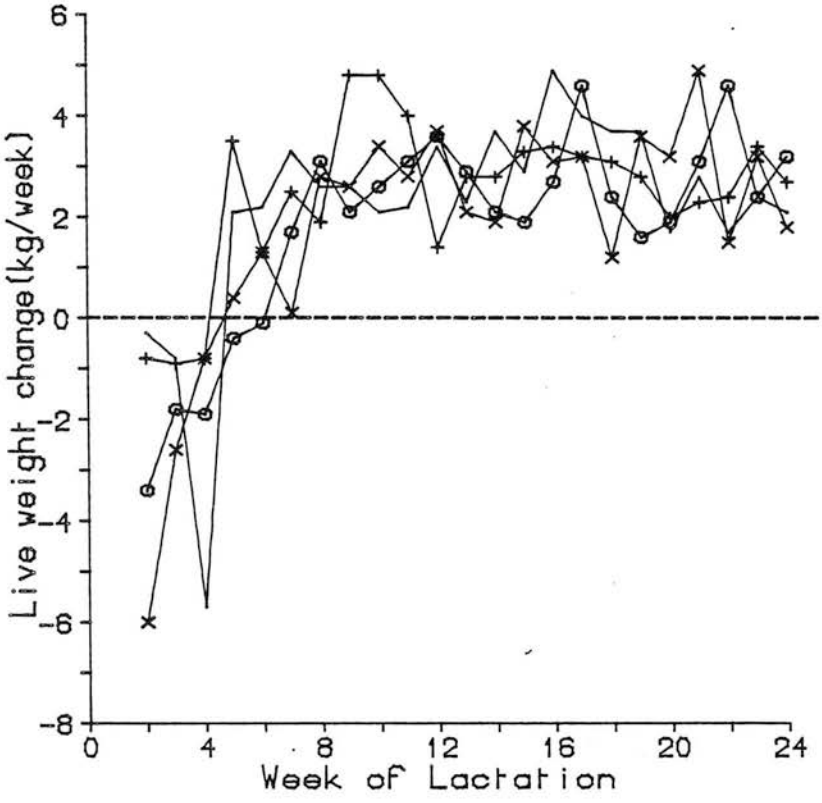
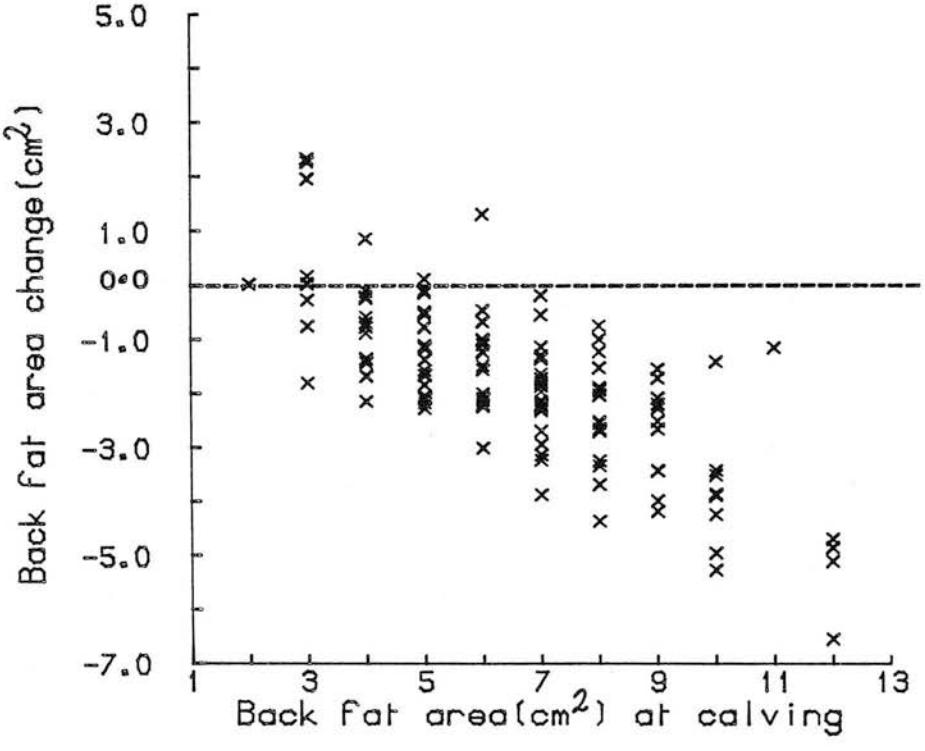


Figure 6.12 :Relationship between calving back fat area (X,cm^2) and back fat area change(Y,cm^2) between calving and week 6 of lactation for years 1 to 4 of experiment.
Y=0.0479(SE,0.0135)-0.0144X(SE,0.00018);R^2=36.0% ,RSD=0.0379



coefficients declined in size as lactation progressed, suggesting that a unit advantage in calving condition is associated not only with a heavier animal, but also a greater decline in LW during lactation.

Similarly to Trial 1 LWC was positively associated ($P < 0.05$) with LW in lactation stage 4 and BS over lactation stages 1-4. A 1 kg increase in LWC (lactation stage 1) was equivalent ($P < 0.05$) to 0.13 kg/week decline in LWC in lactation stage 4 (Table 6.8).

Also, calving LW was positively related ($P < 0.05$) to BS in all stages of lactation, but, as in Trial 1, was negatively associated ($P < 0.05$) with only LWC in lactation stage 1 (weeks 2-6). LWC in this period declined by 0.02 kg/week per kg increase in calving liveweight (Table 6.8).

6.3 Discussion

6.3.1 GENERAL

Liveweight change data in early lactation is affected by gut fill (Broster et al, 1980). Dry matter intake is normally low immediately post-calving (Bines, 1979), therefore calculations of LWC by difference must be subject to gut fill effects. The linear regression of LW on time (Broster et al, 1969, 1975) over a long period from calving could also give inaccurate coefficients due to fat mobilisation in early lactation.

To adjust for low DMI (post-partum), post-calving LW was the mean of two consecutive liveweights recorded within one week of each other in the current study. Similarly, to reduce gut fill effects, weekly liveweights were calculated as the mean of current, preceding and

succeeding weekly LW. Weekly weight change was also calculated weekly rather than over long periods of time to reduce error in the estimation. Moreover, data from condition scoring and ultrasonic measurements of BFA are available in this study to provide a more objective assessment of body fat changes. Correlations between BS and BFA at the same time, at lactation weeks 1, 6, 12 and 18, were 0.53, 0.37, 0.58 and 0.61 ($P < 0.05$). These significant correlations indicate that the two methods are similar in assessing reserves of body fat.

The pattern of LWC in the high yielding dairy cow during lactation is usually a fall in LW in the first weeks of lactation followed by a period of gain (Broster and Broster, 1984). The reasons for this pattern of LWC were previously discussed (Flatt et al, 1969; Coppock et al, 1974; Phipps et al, 1984a,b). A similar trend was observed in the present investigation. In both trials animals lost LW between lactation weeks 2-6. The mature cows of Trial 1, however, lost more weight than the mixture of cows and heifers of Trial 2 (2.47 vs 0.44 kg/week). This contrast is probably owing to the catabolism of body fat by older cows to satisfy energy requirements for high milk production. Animals also lost in both BS and BFA. However, BS loss occurred between calving and lactation weeks 2-6 whereas BFA loss continued until lactation week 12. The differences between the two measures have to be interpreted carefully, taking account of the infinitely variable nature of BFA compared to the discrete measures of BS.

The trends in LW, BS and BFA suggest that liveweights do not reflect accurately changes in body fat. For example, by lactation weeks 13-18, on average, animals had recovered post-partum LW lost but not BS

or BFA lost. This suggests either that the method of calculating LW described failed to correct for gut fill effects or possibly differential growth of lean tissue in relation to fat and bone influenced the different patterns of LW in relation to BS and BFA changes.

Also, the results demonstrate differences between patterns of LWC and estimated energy balance. For example, in Trial 2, on average, animals were estimated to be in positive energy balance in lactation weeks 2-6. It can be argued, however, that 0.06 kg/day LW loss is too small to be estimated accurately by such a variable trait as energy balance. These results indicate the problem of finding a precise estimator of body tissue energy change (Moe et al, 1971).

Linear regression of calving LW on calving condition score suggest that a unit BS is equivalent to 63-177 kg (average 105 kg) in Trial 1 but 149 kg in Trial 2 (Appendix Table A.49). The surprising aspect of the present results was the lack of difference between cows and heifers in these coefficients (Trial 2). Since body fat increases with maturity (Webster, 1980) one would have expected significant differences between parities. Furthermore, Moisey and Leaver (1984) noted that the equivalent LW of one unit BS declined from 75 to 56 kg as the proportion of 2nd and 1st calvers in the experiments decreased. The discrete and subjective nature of condition scoring could be responsible for these unexpected results. For example, correlations between calving BS and LW ranged from 0.54 to 0.68 in the present experiment. Also, the equivalence of LW to a unit of BS differed between years of the present investigation (range 63-177 kg) even though the condition scoring was carried out by one experienced operator.

The present values for the weight change associated with one complete BS are higher than those reported in the literature. Frood and Croxton (1978) reported 28 kg for cows and 17 kg for heifers, Kilkenny (1979) observed 49-64 kg, Wright (1982) found 61-110 kg for different breeds of beef cattle whereas Gordon (1984) reported 75 kg. Thus it would seem that the choice of coefficient will depend on breed, physiological state and age of cattle. This is to be expected for breeds of cattle differ not only in skeletal size but also in distribution of body fat (Wright, 1982).

Moe, Tyrrel and Flatt (1971) observed that the major difficulty in interpreting the adequacy of nutrition of lactation cows, particularly in early lactation, is the lack of precise estimators of body tissue energy change. Body fat, energy and protein estimated from ultrasonic measurements of BFA and equations derived from cow slaughter data showed too great a level of variability to be of much use as accurate predictors of body compositional changes. The results are, however, similar in trend to other estimates reported in the literature. Belyea et al (1978) using whole body potassium-40 counting in lactating dairy cows fed conventional diets revealed average losses of 50 kg body fat and 10 kg body protein during the first 6 weeks of lactation. Bines and Hart (1982), based on data from serial slaughter of dairy cows, observed 8 kg body fat but no protein loss by lactation week 5. In the present investigation body fat and protein loss was estimated as 35.3 and 0.15 kg respectively in the first 6 weeks of lactation (Appendix Table A.48).

6.3.2 EFFECTS OF DIFFERENT FACTORS ON LIVE BODY MEASUREMENTS

6.3.2.1 Environmental Effects

Milk yield and energy intake exercise major effect upon LW, BS and

levels (Broster and Broster, 1984). It was, therefore, anticipated that September calvers, compared to other monthly calving groups, which had higher ME intakes in lactation stages 3 and 4, without higher milk yields, would have higher LW, BS and BFA gains. The higher BS and BFA loss in lactation weeks 1-12 and 1-18 by September calvers is therefore difficult to interpret. This could happen if body fat is preferentially deposited in other areas of the body (eg abdominal) before subcutaneous deposition. Butler-Hogg et al (1985) demonstrated in dairy cattle that subcutaneous fat is preferentially mobilized before abdominal fat. Possibly the reverse is the case for body fat deposition.

6.3.2.2 Effect of Parity

It is generally assumed that immature cows, due to the basic drive to achieve mature size, should gain more weight during lactation than mature cows. This infers that the homeorhetic control of nutrient partitioning during lactation for milk, growth and fattening is not similar across parities. Evidence from body weight change of cattle would tend to support this view (Miller et al, 1969; Strickland and Broster, 1981).

Contrary to the above findings, parity differences in LWC, BSC and BFAC were generally small and non-significant in this study. The lack of significant parity effects in this experiment could be due to:

1. the high milk yields of immature cows;
2. high feed intakes by mature cows in relation to requirements because of ad libitum feeding of high energy mixed diets.

These results are in agreement with observations of Brown et al (1983) that high yielding heifers did not grow during the first 210 days of lactation. These results would therefore tend to suggest that during

the dry period high yielding heifers need to be provided with adequate nutrition to be able to cater not only for growth and pregnancy, but also to replenish body reserves. The slightly lower calving BS of 2nd calvers compared to 1st calvers could therefore be attributed to lack of adequate nutrition during the dry period or that 50-60 day dry period is not long enough. This low BS, under ad libitum feeding during lactation, probably has no detrimental effect on milk yield. Broster et al (1985) showed that cows on low levels of feed from 1st to 2nd lactation showed a change in partition of feed towards body gain rather than milk yield; suggesting that in some cases growth has priority over milk yield in feed partitioning.

Estimates of body fat, protein and energy change from BFAC indicated that heifers of year 4 lost 291.9 and 8.7 g/day and 11.7 MJ/day body fat, protein and energy whereas cows (year 4) lost 308.9 and 7.5 g/day and 12.3 MJ/day in these same variables respectively in lactation weeks 1-6 (Appendix Table A.48). The mobilisation of body protein by heifers is not surprising for Bath et al (1965) demonstrated that heifers have the ability to lose 10 kg of body protein over 15 weeks of underfeeding.

6.3.2.3 Effect of Milk Yield

The lack of significant effect of daily milk yield in lactation week 2 on LW, BFA, LWC, BFAC and BSC, on average, through most subsequent stages of lactation, run contrary to the general principles established under conditions of fixed forage feeding (Broster, 1974, 1976; Broster and Thomas, 1981) where it has been shown that high yielding animals respond less in liveweight gain and more milk yield than low yielding cows. The present observations, however, are in agreement with Korver (1982) and Gordon (1984) who found no effect

of milk yield on LWC of cows fed on different levels of concentrate with forage offered ad libitum. The results of Trigg and Parr (1981) and Davey et al (1983) who could not demonstrate large differences in fat mobilization between cows of high or low breeding index also support this hypothesis; these authors, however, found that high breeding index cows lost more BS than average. These observations tend to suggest that, under ad libitum high quality feed, high yielding cows are capable of consuming enough feed for milk production and body weight gain similar to low yielders.

Between lactation weeks 1-6 high yielding cows (MY_3) were estimated to have mobilized 841.9 and 3.6 g/day and 33.1 MJ/day of body fat, protein and energy respectively whereas low yielding cows (MY_1) mobilized only 776.8 and 17.0 g/day and 30.9 MJ/day of these same traits respectively (Appendix Table A.48). An interesting aspect of the above results is the high amount of protein apparently mobilized by MY_1 animals. These results infer that immature cows, which are liable to be classified as low yielders, usually with less body fat reserves, mobilize some body protein to support milk production in early lactation. A similar pattern has already been described for year 4 heifers. The lack of corroborative data suggests that these results cannot be accepted as precise due to the high standard deviations. Cowan et al (1981), however, observed that heifers producing only 16 kg milk/day and fed ad libitum complete diets were 6 g N/day in positive nitrogen balance in the first 10 weeks of lactation.

6.3.2.4 Effect of Condition Score

The positive association between calving BS and LW and BS loss during lactation in the current investigation are in agreement with previous

reports in the literature (Land and Leaver 1981; Grainger et al, 1982; Garnsworthy and Topps, 1982b; Garnsworthy and Garner, 1985). However, the significant effect of calving BS on BSC and BFAC in lactation weeks 1-18 (but not weeks 1-6 or 1-12) suggests that the rate of fat loss is similar for all condition groups. The amount of fat mobilized over long periods of time differs due to a larger amount available for mobilization in fat animals.

These results run contrary to the previous thesis that fat animals have greater fat loss in early lactation due to low feed intakes in relation to requirements (see Broster and Broster, 1984). Furthermore, evidence with sheep indicated that rate of lipolysis during early lactation was proportional to fat cell size (Anonymous, 1984). The feeding of high energy complete diets in the present study was probably responsible for the lack of calving BS effect on BSC in early lactation. Alternatively, it could be because BSC takes some time to show (Broster et al, 1980). A decline in BS loss due to increased feeding level post-calving has been reported (Grainger et al, 1982).

6.3.2.5 Effect of Calving Liveweight

The significant positive association between calving LW and BS within different stages of lactation was expected since BS measures body fatness. This is consistent with studies by other workers (Garnsworthy and Topps, 1982b; Wildman et al, 1982). The lack of significant relationship between calving LW with subsequent BFA (Trial 1) is contrary to the report of Neilson et al (1983) using a subset of the present data. The adjustment of the data to a common BS was probably responsible for this discrepancy; BS and BFA are positively correlated as demonstrated previously.

One surprising aspect of the present data was the significant inverse relationsip between calving LW and LWC in lactation weeks 2-6. This suggests two possible explanations:

1. Due to moderate repeatability, condition scoring failed to adjust all data to the same true fatness levels.
2. LWC, which is estimated with indifferent accuracy in early lactation (Moe et al, 1971), was not satisfactorily estimated.

6.3.2.6 Effect of Liveweight Change

Average weekly LWC within a stage of lactation should be closely related to the corresponding average LW in that stage. This should be automatic since weight changes resulting from growth or adipose tissue changes will automatically be reflected in an increased total body weight. It is therefore surprising that LWC was only positively and significantly associated with LW in lactation stages 1, 2 (Trial 1) and 4 (Trial 2). A possible explanation for these results is lack of homogeneity across cows in the relationship between LWC and LW. Some cows probably have more fat whereas others more water and protein in their weight changes; thus affecting the real size of LWC. Miller, Hooven and Creegan (1969) also noted that LWC (calculated as difference between calving LW and end of lactation LW) was significantly associated with LW only after lactation week 17. These results further show the problems of estimating or using LWC.

The present data also tend to suggest that the influence of LWC on BS and BFA and their changes may not be immediate but may have some residual or cumulative effect. LWC was noted to have a significant positive relationship with BS (over lactation stage 1-4) and BFA (lactation week 12). Also, LWC in lactation stage 1 was significantly

and positively associated with BSC (between lactation weeks 1-12 and 1-18) and BFAC (lactation weeks 1-12). This is probably in line with the suggestion that BS has the disadvantage of being relatively slow to show the necessary changes in body tissue fat (Broster et al, 1980).

Interestingly, there was a lack of significant effect of LWC in weeks 2-6 of lactation on LWC in subsequent stages of lactation. Also, there was low correlation between LWC or BSC in consecutive lactations of the same cow (Appendix Table A.47). This suggests that LWC or BSC is more dependent on variations in milk yield and feed intake and is thus not an individual animal attribute.

6.4 Conclusion

During the experiment LW and BS declined within the first 6 weeks of lactation followed by a period of gradual LW and BS gain. The results, however, showed an interesting lack of correspondence in time between LWC and BSC; in some instances animals tended to gain LW while losing condition.

Environmental and animal (in the immediate post-partum period) factors accounted for 39.0-67.7% of the variation in LW and BS patterns, but only 13.3-39.4% of LWC. The influence of these factors generally declined as lactation advanced.

Milk yield in lactation week 2 was negatively but non-significantly correlated with LWC, BSC and BFAC in most stages of lactation. The cumulative effect of these changes resulted in significantly lower BS values for high compared with low yielding cows in most stages of lactation.

The higher the calving condition score, the greater was the subsequent

condition score, liveweight and backfat area loss during lactation.

Weekly weight change should normally be expected to be automatically and significantly related to the corresponding LW through the stages of lactation, but probably because of lack of homogeneity in size of LWC this was not the case. LWC in later stages of lactation was not significantly influenced by LWC in lactation weeks 2-6. However, LWC in lactation weeks 2-6 was positively and significantly correlated with BSC and BFAC in lactation weeks 1-12 but not weeks 1-6. Within cow correlations of LWC in consecutive lactations were small.

Parity had no significant influence on LWC, BSC and BFAC. LW, as was expected, however, increased with increasing parity. There was an 8% depression in calving BS from 1st calving to 2nd calving for the same animal. The regression of calving LW on calving BS showed parallel slopes for cows and heifers. A 1-unit increase in calving BS was associated with 105 kg increase in LW for cows (years 1-4), but 149 kg for cows and heifers (years 4 and 5).

Estimation of body energy, protein and fat from ultrasonic measurements of BFA and equations derived from cow body composition data all showed considerable variability. The results, however, suggest that heifers probably mobilize some body protein early in lactation.

It is concluded that a major positive physiological driving force in body fat loss during lactation is the size of body fat reserves at calving. LW and BS loss, on average, in the first 6 weeks of lactation is therefore inevitable even under the present system of ad libitum feeding. Condition score change is slow to show during lactation but appears to reflect body fat changes more accurately than LWC. Corresponding body composition change data are

needed to confirm this. Also, further research is needed to determine the order of body fat deposition in abdominal and subcutaneous zones and the effect on BSC and LWC. The need, therefore, for better body composition data relating to LWC for the building of feed intake, milk yield and nutrient utilizations models for dairy cows cannot be over-emphasised.

7 EATING BEHAVIOUR

7.1 Materials and Methods

7.1.1 ANIMALS

Four experimental periods (to be called Investigations 1-4) were devoted to animal eating behaviour studies. The system of feeding, management and animal recordings were described in Chapter 2. In addition, in Investigation 4, the animals were within one week of calving measured for body length, height at the withers (using a measuring stick) and heart girth (using a steel tape graduated in millimetres as shown in Figure 2.1 (Chapter 2).

The composition of diets fed during the experimental periods is detailed in Appendix Table A.66.

7.1.2 DATA COLLECTION

All animals were observed twice weekly on Mondays and Tuesdays in Investigations 1, 2 and 3 and on Tuesdays and Wednesdays in Investigation 4. Observations on time spent eating by animals commenced 5 minutes after fresh feed was offered at 08.30 h and continued at 5 min intervals, except during feed intake recording and milking until 2 h after PM milking (17.30 or 19.30 h). An animal was recorded as eating during a 5 min interval when observed with its head in a feed bin, prehensing feed with some around its muzzle or appearing from the corners of the mouth. A 5 min recording interval was chosen because initial observations had revealed no eating bout less than 5 min in length. Furthermore, according to Mullen, Hurnik and Ralph (1980) and Smith and Hodgson (1984), where

more than 30 animals are involved in an investigation of eating behaviour, 10 min recording interval provides relatively accurate estimate of time budgets similar to continuous observations.

The recording day was partitioned into 3 or 4 periods based on a pattern of eating recorded from the preliminary observations. Periods were selected so as not to interfere unduly with normal pattern of eating, at the end of each period, when feed intake was recorded. Feed eaten in the daytime was recorded as:

Feed offered - feed left over 2 h after PM milking

Night feed intake was recorded as:

Total daily feed intake - daytime feed intake

Feed on offer was sampled during recording days and analysed for DM and other components (see Chapter 2).

Other animal behaviour such as time spent ruminating or drinking water could not be recorded. This was because animals performing these behaviours could not be seen from the recording area (feeding alley).

7.1.3 INVESTIGATION 1

Forty animals (26 heifers and 14 parity 2 cows) in lactation weeks 17-32, all part of the year 5 study described in Chapter 2, were observed between 10th April and 3rd May, 1984 under complete confinement in a cubicle house. Daily observations lasted 9 h from 08.30 to 17.30 h; during which time 2 h was spent on routines (feed recording and milking). The day was divided into 3 periods:

(a) Period 1 - from fresh feed offering (feeding) to 2 h after feeding.

(b) Period 2 - from 2.5 h after feeding to 5.5 h after feeding.

(c) Period 3 - from the end of PM milking to 2 h after milking.

Individual feed intakes were recorded at the end of each period for all heifers, but only at the end of period 3 for 2nd parity cows.

7.1.4 INVESTIGATIONS 2 AND 3

The same animals used in Investigation 1 were observed in Investigations 2 and 3. The animals were in weeks 22-36 of lactation (Investigation 2) and weeks 28-42 of lactation (Investigation 3) when observations began and were recorded between 11th May and 12th June and between 18th June and 3rd July, 1984 for Investigations 2 and 3 respectively. Management was similar to that described under Investigation 1. However, cows were milked 2 h later and daily recordings were collected between 08.30 and 19.30 h. In addition, animals were allowed in Investigation 2, in the last 5 weeks of recording, to go out of the cubicle house voluntarily to a 0.5 ha exercise paddock, bare of grass, within 30 min after feeding for a period of 2.5 h. Similarly in Investigation 3, the animals were allowed out within 1 h of feeding for a period of 4 h. The day was divided into 4 periods:

(a) Period 1 - feeding to 2 h after feeding.

(b) Period 2 - from 2.5 h after feeding to 5.5 h after feeding.

(c) Period 3 - from 6 h after feeding to 8 h after feeding.

(d) Period 4 - from end of PM milking to 2 h after milking.

Feed intake was recorded for heifers and cows as described for Investigation 1.

7.1.5 INVESTIGATION 4

Thirty-three animals (11 heifers, 11 parity 2 and 11 parity 3 cows) were observed from week 1 to 8 of lactation between 14th September and 9th December, 1984 under complete confinement in a cubicle house. The day was partitioned into periods as described under Investigations 2 and 3 and

feed intake at the end of each period was recorded for all animals.

7.1.6 DATA ANALYSIS

Individual meals and inter-meal intervals were determined by survivorship curves (Wiepkema, 1971; Metz, 1975) of meal interval frequencies on meal intervals (Figure 7.1). The rationale behind this was given in detail in Chapter 1.1.3.6. Briefly, there are two types of intervals between eating bouts, short breaks with high probability of ending during which the animal grooms or licks itself or goes to drink water, and longer breaks with low probability of ending. The short breaks are usually considered to occur within a meal whereas the longer breaks are considered to occur between meals. The survivorship curve is therefore an attempt to separate these two types of gaps or breaks between eating bouts. The important property of such a plot is that it is linear if the probability of the break in eating ending is high but concave where the probability is low. The point of inflexion between the linear and concave parts is chosen as the minimum inter-meal interval. Data were pooled for all animals in each Investigation and for Investigations 2 and 3 to provide enough data for the survivorship curve plots. Visual inspection of the survivorship curves reveals two types of intervals: short intervals within eating bouts (5-20 min - Investigations 1, 2 and 3, and 5-25 min - Investigation 4) and longer inter-meal intervals in all investigations. A meal was therefore defined as eating activity followed by at least 20 min (Investigations 1-3) or 25 min (Investigation 4) of non-eating activity. Meal duration was time spent on a meal, meal size was the ratio of daytime dry matter intake (DDMI) to meals eaten and rate of eating was ratio of DDMI to total time spent eating.

Figure 7.1 : Survivorship curves for intermeal intervals

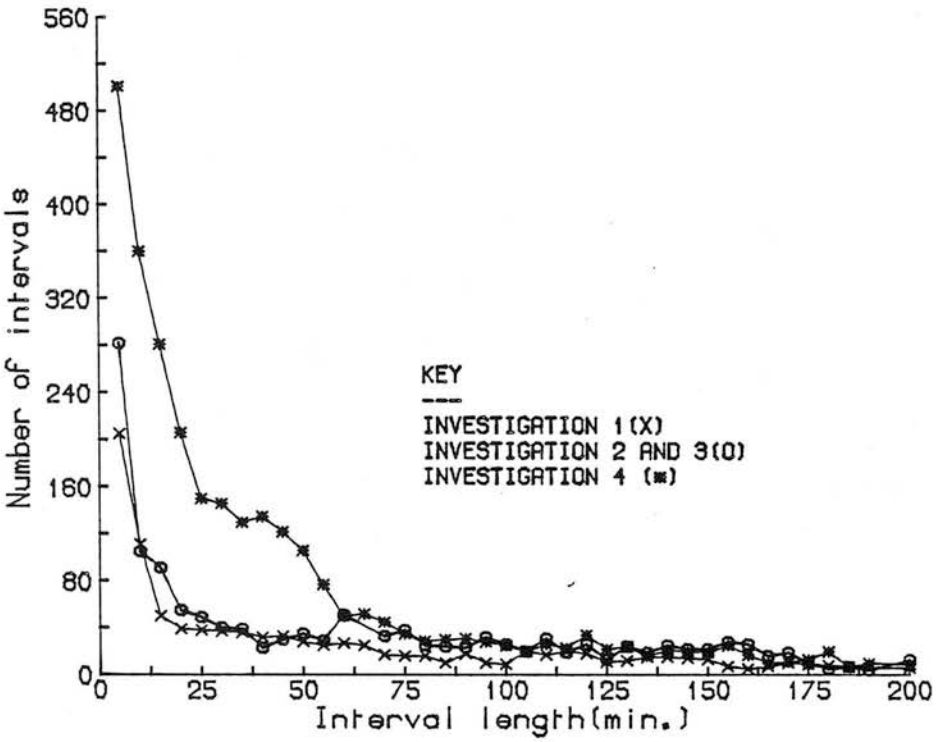
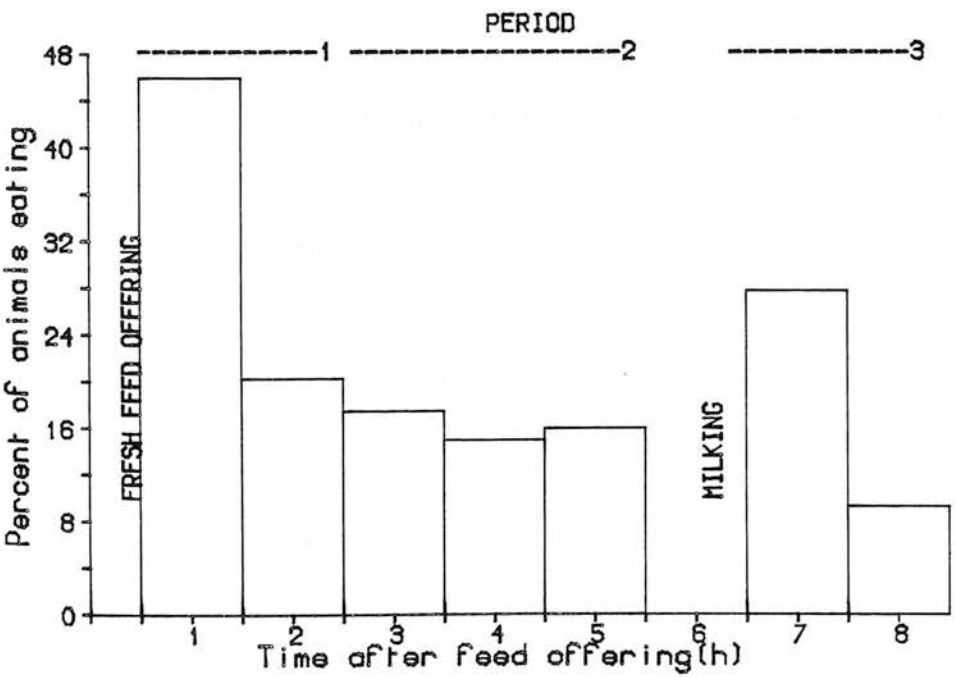


Figure 7.2 : Frequency distribution of percent of animals eating - Investigation 1



Eating behavioural traits (number of meals eaten, meal size, time spent eating, rate of eating, meal duration, DDMI and night dry matter intake) and other animal characteristics were subjected to analysis of variance (Genstat, 1984). Sources of variation tested for significant differences were: parities (L), periods of day (P) and cows (C) within parities.

In Investigation 4 weeks of lactation were divided into 2 stages (S): Stage 1 (weeks 1-4) and Stage 2 (weeks 5-8). The data were analysed as a 3 x 4 factorial (3 parities x 4 daily periods) and as a 3 x 2 factorial (3 parities x 2 stages of lactation). Daily eating behavioural traits (now referred to as eating traits) were adjusted by covariance analysis using daily FCM yield and LW as covariates; to test if sources of variation in these traits were due to either FCM yield or LW.

Simple correlation coefficients were computed between eating traits and animal production characteristics.

7.2 Results

7.2.1 INVESTIGATION 1

Table 7.1 presents means of eating traits and animal production characteristics. Mean LW, BS and milk yield achieved during the experiment were 606 kg, 2.75 units and 21.2 kg/day respectively. There was considerable variation between animals in eating traits. On average, the animals spent 94.3 min (range 25-180 min) of the 9 h recording period eating 3.4 meals, each averaging 2.5 kg DM. The average intervals between first and second meals and between all meals were 99.8 and 117.6 min respectively. The daytime dry matter intake (DDMI) of 8.5 kg was 56.7% of the total dry matter intake (TDMI). The distribution of eating

Table 7.1 Means for eating behavioural and production traits - Investigation 1

TRAIT	MEAN	SD	MINIMUM	MAXIMUM
Live body weight (kg)	606	65	455	755
Condition score (1-5 units)	2.75	0.10	1.75	3.75
Milk yield (kg/day)	21.2	2.41	9.0	29.4
First inter-meal interval (min)	99.8	65.4	20.0	320.0
All inter-meal intervals (min)	117.6	65.7	35.3	410.6
Meal size (kg)[a]	2.51	0.78	1.10	7.28
Number of meals	3.4	0.92	1.0	6.0
Time spent eating (min)	94.3	30.9	25.0	180.0
Daytime dry matter intake (kg)	8.5	1.58	4.9	19.6
Night dry matter intake (kg)	6.5	1.50	0.7	14.4
Number of animals eating (%)[b]	21.1	2.00		
Number of animals lying (%)[b]	44.6	2.96		

[a] DDMI ÷ Number of meals

[b] Calculated from daily records

Table 7.2 Effect of parity (L) (adjusted for stage of lactation) and period of day (P) on feeding behavioural traits Investigation 1

TRAIT	PERIOD OF DAY 1	2	3	SE OF DIFFERENCE Period	Parities within P1	P2	P3
Number of meals:							
L1	1.36	0.96	1.25				
L2	1.10	0.95	1.12				
All	1.27	0.96	1.18	0.54	0.07[b]	0.08	0.09
Time spent eating (min):							
L1	45.1	25.9	28.8				
L2	31.5	25.5	26.6				
All	40.5	25.8	28.0	1.34[c]	2.40[c]	2.60	2.24
Meal duration (min):							
L1	36.2	28.2	21.6				
L2	31.2	26.6	24.2				
All	30.1	27.6	22.5	1.20[c]	1.99[a]	1.69	1.50
Dry matter intake (kg)*	3.64	1.87	3.05	0.158[c]			
Meal size (kg)*	2.61	1.90	2.35	0.216[b]			
Rate of eating (kg/5 min)*	0.41	0.36	0.53	0.026[b]			

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$

* Recorded for only heifers

activities of animals is shown in Figure 7.2. Within every 5 min of recording 21.1 and 44.6% of animals, on average, were either eating or lying down respectively. Eating activities were greatest in the h interval after feeding and after milking. About 46 and 28% of the animals, on average, were observed to eat at these times respectively.

These patterns of eating activities were reflected in significant ($P < 0.05$) period differences in most eating traits (Table 7.2). Thus eating traits were higher in Period 1 (2 h after feeding), declined to low values in Period 2 but increased again to high values (but not equal levels as Period 1) in Period 3 (2 h after milking).

The eating traits of heifers were significantly ($P < 0.05$) higher in Period 1 than cows and this was reflected in significant differences for cows and heifers on days of recording. Milk yield, time spent eating and number of meals eaten during a recording were significantly ($P < 0.05$) higher for heifers than cows. Cows, however, were significantly ($P < 0.05$) heavier and had a significantly higher rate of eating than heifers (Appendix Table A.60). Differences between cows and heifers were not due to differences in LW or milk yield. Animals within heifer or cow groups also significantly ($P < 0.05$) differed in eating traits even when adjusted for differences in LW and milk yield.

As would be expected, increasing DDMI was positively associated ($P < 0.05$) with time spent eating ($r = 0.419$), rate of eating ($r = 0.444$) and meal size ($r = 0.776$). Dry matter intakes within periods (PDMI) were very highly correlated ($P < 0.01$) with time spent eating within the period ($r = +0.648 - +0.735$) indicating that about 50% of the variation in DDMI is due to time spent eating (Table 7.8). One striking feature of these

results was the negative relationship between night dry matter intake (NDMI) and DDMI ($r = -0.335$, $P < 0.05$) and time spent eating ($r = -0.216$).

Increasing milk yield as expected was associated with significant increases in DDMI ($r = 0.557$, $P < 0.01$) and number of meals eaten ($r = 0.510$, $P < 0.05$) but surprisingly non-significant increases in time spent eating ($r = 0.216$) (Appendix Table A.65). Condition score and LW were poorly correlated with eating traits.

Correlation coefficients between meal size and pre- and post-meal intervals, which provide information on hunger and satiety mechanisms were low ($r = +0.210$ ($P < 0.05$) and $r = -0.051$, respectively). Similarly, correlations between meal duration and pre- and post-meal intervals were also low ($r = +0.167$ and -0.065 respectively).

7.2.2 INVESTIGATIONS 2 AND 3

Table 7.3 provides mean, minimum and maximum values of eating traits and animal characteristics. The animals produced 18.0 and 17.4 kg/day milk for Investigations 2 and 3 respectively. In Investigation 2 where animals were allowed 2.5 h outdoors they spent 106.6 min (range 30-195) eating and ate 9.1 kg DM (70.0% of TDMI) in 4.5 meals during 11 h of recording. In Investigation 3 where they were allowed out for 4 h they surprisingly spent 121.9 min eating 10.8 kg DM (72% of TDMI) in 3.8 meals.

In both investigations peaks of eating activity occurred within 1 h of feeding, returning from the exercise paddock and milking (Figure 7.3). The average proportion of animals observed eating at these times were

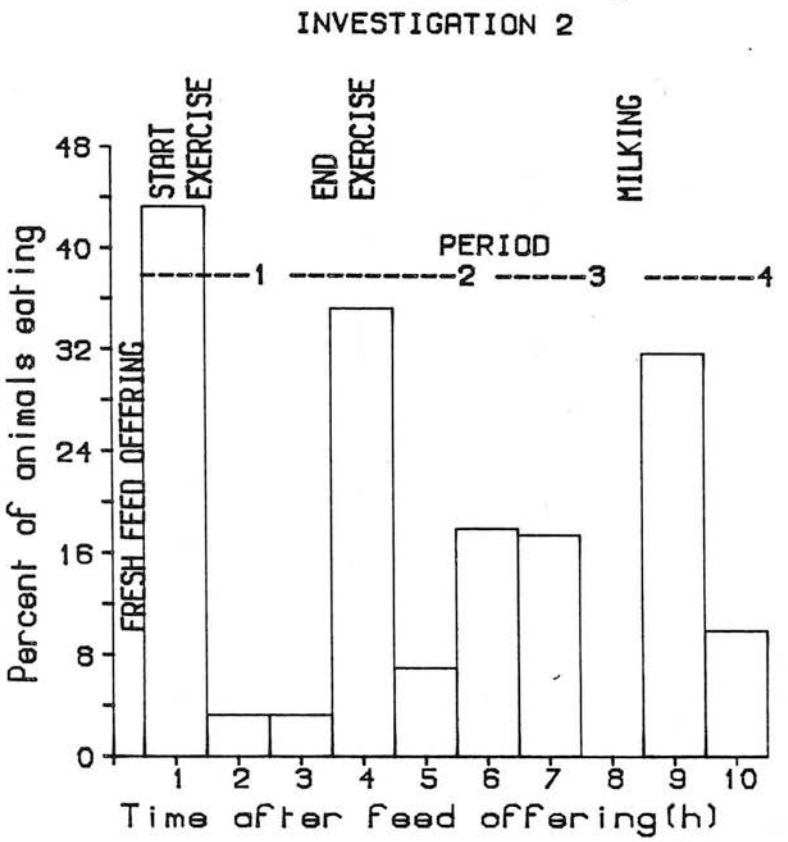
Table 7.3 Means of eating behavioural and production traits - Investigations 2 and 3

	INVESTIGATION 2				INVESTIGATION 3			
TRAIT	**Mean**	**SD**	**Minimum**	**Maximum**	**Mean**	**SD**	**Minimum**	**Maximum**
Liveweight (kg)	607	67	460	735	622	59	480	760
Condition score (1-5 units)	2.81	0.10	1.75	3.75	2.82	0.38	2.00	3.75
Milk yield (kg/day)	18.0	1.11	9.6	26.2	17.4	2.92	6.4	25.4
First inter-meal interval (min)	148.7	70.6	20.0	410.0	218.0	64.2	20.0	415.0
All inter-meal intervals (min)	124.5	45.4	30.8	395.1	176.0	58.0	40.6	416.2
Meal size (kg)[a]	2.12	0.47	0.70	4.52	2.92	0.99	1.05	5.64
Number of meals	4.5	0.98	1.0	7.0	3.8	0.91	1.0	6.0
Time spent eating (min)	106.6	40.2	30.0	195.0	121.9	30.9	45.0	185.0
Daytime dry matter intake (kg)	9.1	2.56	6.3	17.7	10.8	2.03	5.6	18.9
Night dry matter intake (kg)	4.0	1.57	0.0	9.4	4.2	1.63	0.0	9.7
Number of animals eating (%)[b]	19.6	3.6			22.0	2.27		
Number of animals lying (%)[b]	42.3	4.6			45.1	2.79		

[a] DDMI - Number of meals

[b] Calculated from daily records

Figure 7.3 : Frequency distribution of percent of animals eating - Investigations 2 and 3



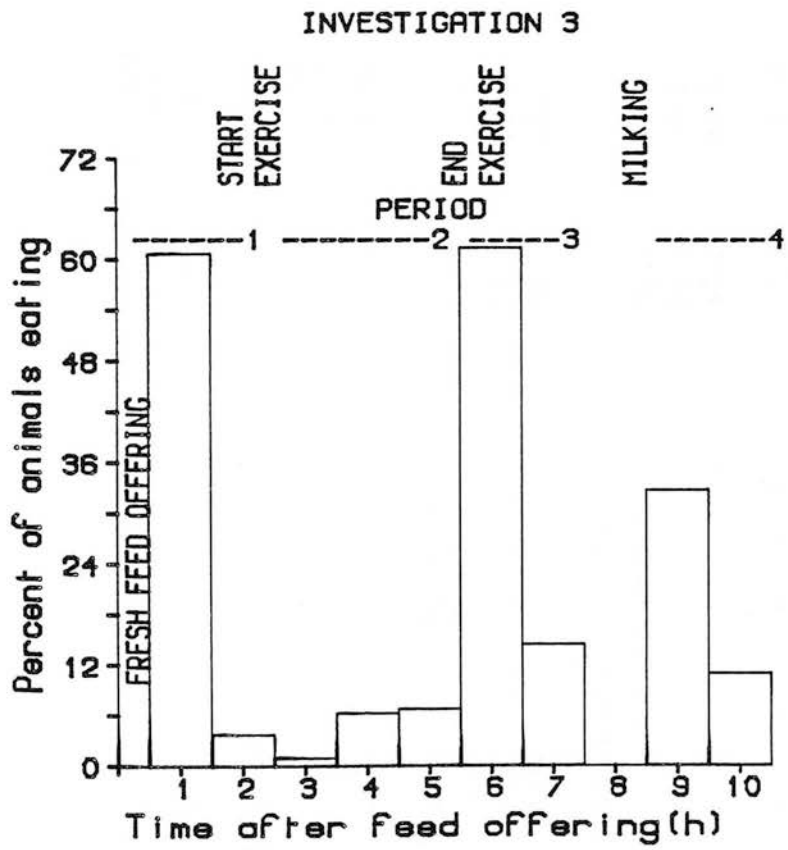


Table 7.4 Effect of parity (L) (adjusted for stage of lactation) and period of day (P) on animal feeding behavioural traits - Investigation 2

TRAIT	PERIOD OF DAY 1	2	3	4	SE OF DIFFERENCE Period	Parities within P1	P2	P3	P4
Number of meals:									
L1	1.16	1.09	1.14	1.15					
L2	1.04	1.02	0.99	1.13					
All	1.14	1.06	1.08	1.14	0.032[b]	0.05[b]	0.07	0.06[b]	0.06
Time spent eating (min):									
L1	27.9	27.3	29.3	26.9					
L2	26.8	22.1	23.7	24.8					
All	27.5	25.6	27.4	26.1	0.194	1.46	1.83[b]	1.79[b]	1.81
Meal duration (min):									
L1	24.1	25.1	25.7	23.4					
L2	25.9	20.9	23.9	21.9					
All	24.2	24.1	25.5	22.9	0.179[c]	1.50	1.36[a]	1.59	1.27
Dry matter intake (kg)*	2.99	2.56	2.19	2.29	0.132[b]				
Meal size (kg)*	2.59	2.35	1.92	1.99	0.310[b]				
Rate of eating (kg/5 min)*	0.52	0.47	0.39	0.41	0.031[b]				

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$

* Recorded for only heifers

Table 7.5 Effect of parity (L) (adjusted for stage of lactation) and period of day (P) on animal feeding behavioural traits - Investigation 3

TRAIT	PERIOD OF DAY 1	2	3	4	SE OF DIFFERENCE Period	Parities within P1	P2	P3	P4
Number of meals:									
L1	1.11	0.32	1.45	1.04					
L2	1.04	0.13	1.30	1.12					
All	1.08	0.25	1.40	1.08	0.037[c]	0.04	0.06[b]	0.08	0.08
Time spent eating (min):									
L1	40.2	9.0	53.1	26.8					
L2	35.0	3.1	44.1	26.2					
All	38.3	6.9	50.0	26.6	0.260[c]	1.70[b]	1.75[b]	2.93[b]	2.14
Meal duration (min):									
L1	36.3	28.1	36.7	25.8					
L2	33.7	23.8	33.9	23.4					
All	35.5	27.6	35.7	24.7	0.240[c]	1.75	1.46[b]	2.15	1.63
Dry matter intake (kg)*	3.76	0.91	4.23	2.17	0.152[c]				
Meal size (kg)*	3.48	3.63	3.02	2.01	0.310[c]				
Rate of eating (kg/5 min)*	0.47	0.49	0.40	0.40	0.030[b]				

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$

* Recorded for only heifers

0.44, 0.35 and 0.32 respectively for Investigation 2 and 0.67, 0.62 and 0.33 respectively for Investigation 3. Few animals returned from the exercise paddock to eat until they were driven back in.

These peaks of eating activity resulted in significant differences ($P < 0.05$) between periods in most eating traits except time spent eating in Investigation 2. In Investigation 2 high values of these traits generally occurred in Period 1 and low values in Period 3 (immediately following the return of the animals from the paddock) probably due to the peak of eating activity in Period 2. In Investigation 3, on the other hand, the lowest values occurred in Period 2 (time in the exercise paddock - Tables 7.4 and 7.5).

In both investigations, milk yield; time spent eating, meals eaten, and DDMI during a recording day were significantly ($P < 0.05$) higher for heifers than cows. Parity differences in number of meals eaten in Investigation 2 and most eating traits in Investigation 3 were associated with differences between the two groups in LW and milk yield. As observed in Investigation 1, animals within parities in Investigations 2 and 3 differed significantly ($P < 0.05$) in eating traits which could not be explained by variation in LW and milk yield (Appendix Tables A.61 and A.62).

An increase in DDMI in both investigations was due to longer time spent eating. This relationship was especially strong within periods ($r = +0.169$ - $+0.587$ for Investigation 2 and $r = 0.264$-0.651 for Investigation 3). Only in Investigation 3 was the number of meals eaten and DDMI highly correlated ($r = 0.690$, $P < 0.01$). As noted in Investigation 1 NDMI was inversely related to DDMI ($r = -0.088$ for Investigation 2 and -0.346,

$P < 0.05$ for Investigation 3) and in time spent eating ($r = -0.505$ to -0.765, $P < 0.01$).

Correlation coefficients between animal characteristics and eating behavioural traits were mostly low except for milk yield which was associated with number of meals eaten in Investigation 3 ($r = 0.471$, $P < 0.05$ - Appendix Table A.65).

The data pooled from Investigations 2 and 3 indicate that pre- and post-meal intervals were significantly correlated ($P < 0.05$) with meal size ($r = +0.319$ and -0.346 respectively) and meal duration ($r = +0.322$ and -0.303 respectively).

7.2.3 INVESTIGATION 4

The means of eating traits and animal production characteristics are presented in Table 7.6. During the investigation the animals, on average, produced daily 28.5 kg (range 16.3-39.8) milk. The animals also, on average, spent 105.5 min eating 10.6 kg DM in 4.85 meals in 11 h of recording.

Main eating activity was similar for all parities, with peaks of eating activity occurring within 1 h of feeding and milking (Figure 7.4). This pattern of eating activity was reflected in differences between periods of day in all eating traits. Most eating traits significantly ($P < 0.05$) declined from Period 1 to Period 3 and then increased again after milking (Period 4). This is shown in Table 7.7.

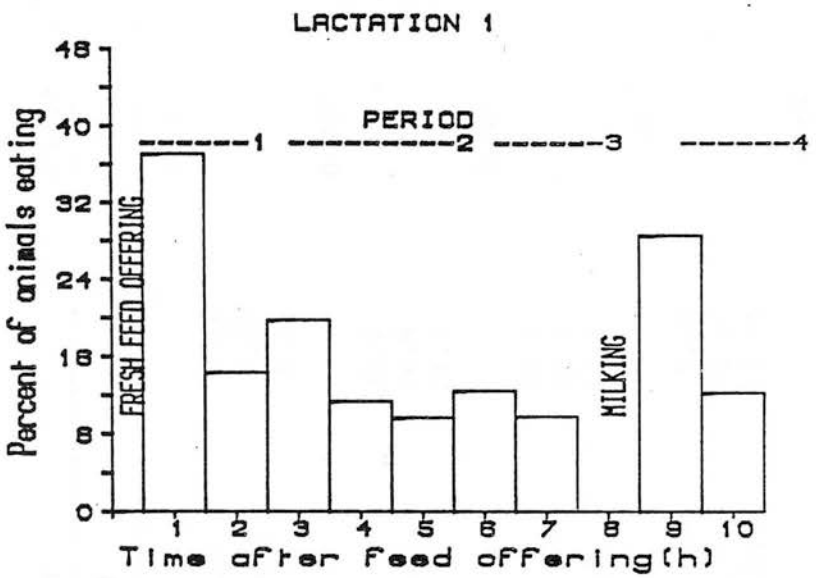
Cows of different parities differed significantly ($P < 0.05$) in most eating traits. Thus even though parity 3 produced significantly more FCM and were heavier, yet time spent eating, number of meals eating, number of

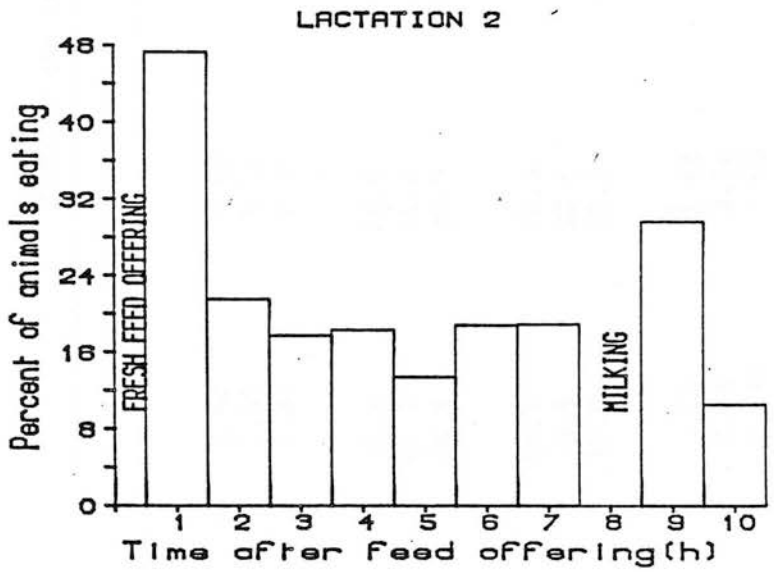
Table 7.6 Means of eating behavioural and production traits- Investigation 4

TRAIT	Mean	SD	Minimum	Maximum
Liveweight (kg)	570	46	475	686
Condition score (1-5 units)	2.68	0.23	2.06	3.56
Milk yield (kg/day)	28.5	5.86	16.3	39.8
First inter-meal interval (min)	122.0	36.3	50.0	235.0
All inter-meal intervals (min)	128.2	28.8	62.8	220.7
Meal size (kg)[a]	2.19	0.37	1.37	3.55
Number of meals	4.85	0.63	3.00	7.0
Time spent eating (min)	105.5	23.8	46.3	170.0
Daytime dry matter intake (kg)	10.55	1.93	6.01	16.20
Night dry matter intake (kg)	5.45	1.25	3.31	9.12
Wither height (cm)	135.1	2.77	130.0	141.0
Heart girth (cm)	195.2	10.80	151.5	208.0
Body length (cm)	155.8	8.14	139.0	186.0
Calving condition score (1-5 units)	2.77	0.27	2.50	4.00
Calving liveweight (kg)	571	60	455	690

[a] DDMI ÷ number of meals

Figure 7.4 : Frequency distribution of percent of animals eating - Investigation 4





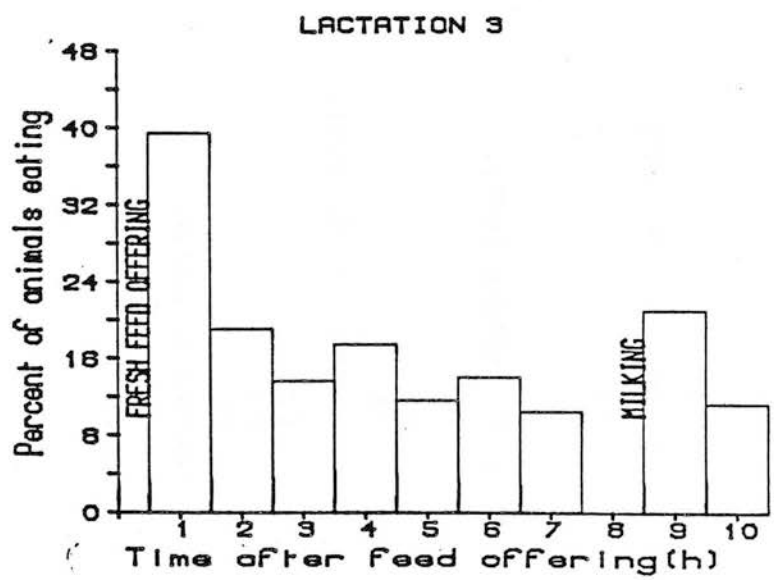


Table 7.7 Effect of parity (L) and period of day (P) on eating behavioural traits - Investigation 4

TRAIT	PERIOD OF DAY 1	2	3	4	SE OF DIFFERENCE L	P
Number of meals:					0.032^{c}	0.036^{c}
L1	1.41	1.09	0.95	1.41		
L2	1.38	1.36	1.09	1.23		
L3	1.34	1.18	0.91	1.13		
Time spent eating (min):					0.96^{c}	1.08^{c}
L1	33.8	20.0	14.4	27.0		
L2	41.2	31.5	21.9	26.9		
L3	36.3	26.5	14.5	21.4		
Meal duration (min):					0.68^{c}	0.77^{c}
L1	24.1	18.5	15.2	19.1		
L2	30.4	23.5	20.1	21.8		
L3	27.9	22.1	16.0	18.7		
Dry matter intake (kg):					0.092^{c}	0.104^{c}
L1	3.13	1.84	1.38	2.62		
L2	4.08	3.16	2.16	2.80		
L3	3.74	2.69	1.52	2.44		
Meal size (kg):					0.064^{b}	0.073^{c}
L1	2.26	1.71	1.49	1.88		
L2	3.02	2.36	2.01	2.31		
L3	2.80	2.31	1.66	2.14		
Rate of eating (kg/5 min):					0.029^{c}	0.032^{a}
L1	0.48	0.48	0.57	0.40		
L2	0.53	0.50	0.52	0.64		
L3	0.52	0.54	0.54	0.74		

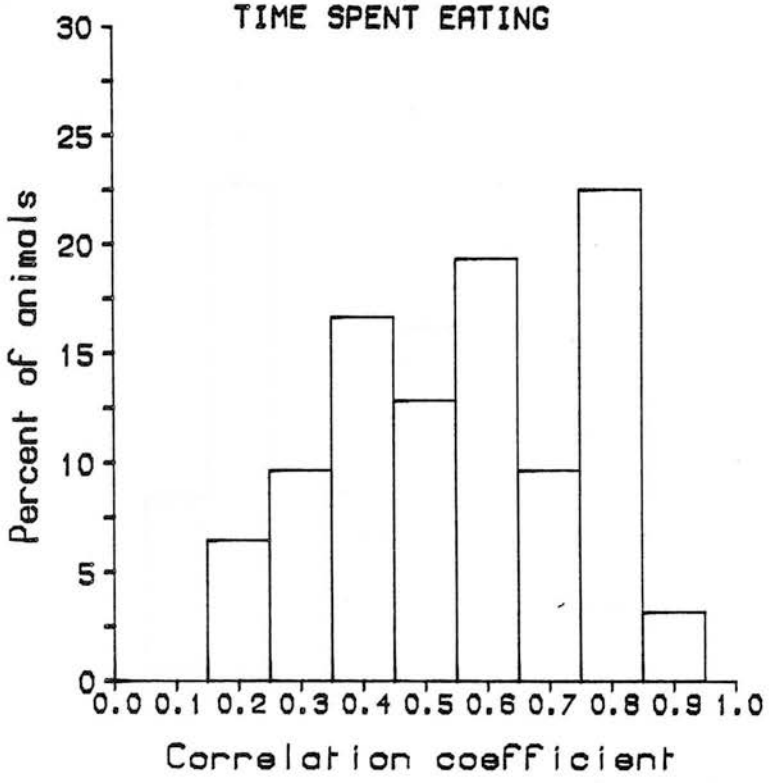
a = $P < 0.05$; b = $P < 0.01$; c = $P < 0.001$

Table 7.8 Correlations between within period dry matter intakes and other eating behavioural traits per period of day and investigation (E)

TRAIT	PERIOD OF DAY 1	2	3	4	All
Meal size					
E1	0.652**	0.727**	0.879**	-	0.776**
E2	0.800**	0.681**	0.932**	0.857**	0.768**
E3	0.793**	0.891**	0.735**	0.760**	0.764**
E4	0.740**	0.736**	0.659**	0.652**	0.696**
Rate of eating					
E1	0.074	0.176	0.623**	-	0.444**
E2	0.309*	0.144	0.594**	0.610**	0.461**
E3	0.346*	0.449*	0.407**	0.309	0.423**
E4	0.258	0.251	0.074	-0.228	0.278
Meal duration					
E1	0.497**	0.467**	0.169	-	0.289
E2	0.357*	0.372*	0.240	0.057	0.381*
E3	0.378*	0.534**	0.070	0.433**	0.365*
E4	0.454**	0.569**	0.448**	0.548**	0.445*
Number of meals					
E1	0.246	0.221	0.079	-	-0.031
E2	0.096	0.309	0.058	0.202	0.188
E3	0.388*	0.246	0.157	0.370*	0.690**
E4	0.354*	0.605**	0.717**	0.554**	0.475*
Time spent eating					
E1	0.735**	0.720**	0.648**	-	0.419**
E2	0.473**	0.585**	0.278	0.169	0.360*
E3	0.651**	0.651**	0.264	0.642**	0.504**
E4	0.685**	0.807**	0.781**	0.762**	0.5453**

** $P < 0.01$; * $P < 0.05$

Figure 7.5 : Frequency distribution of correlation coefficients of drymatter intake with time spent eating and number of meals eaten for Investigation 4



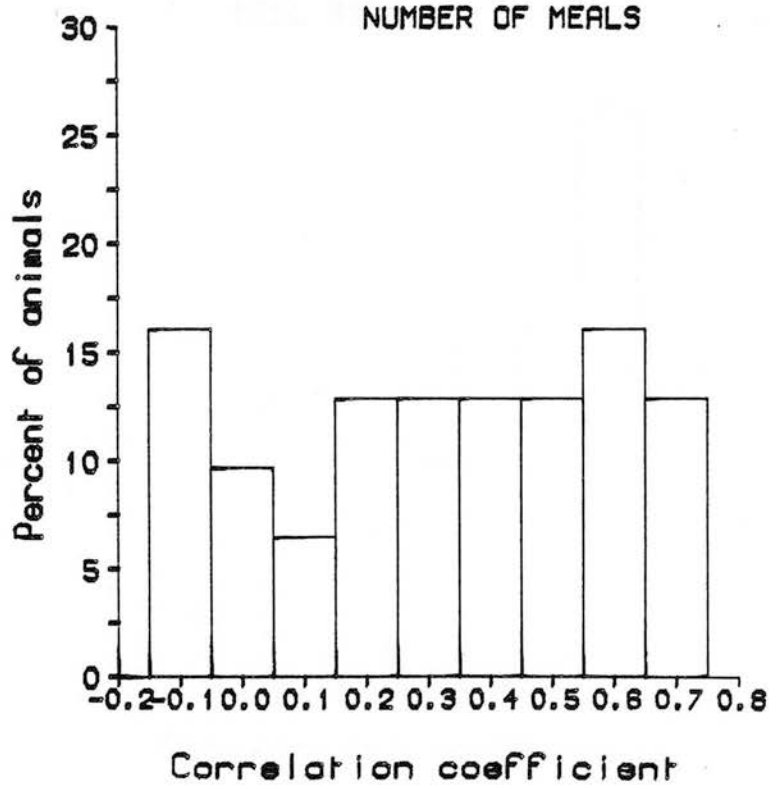
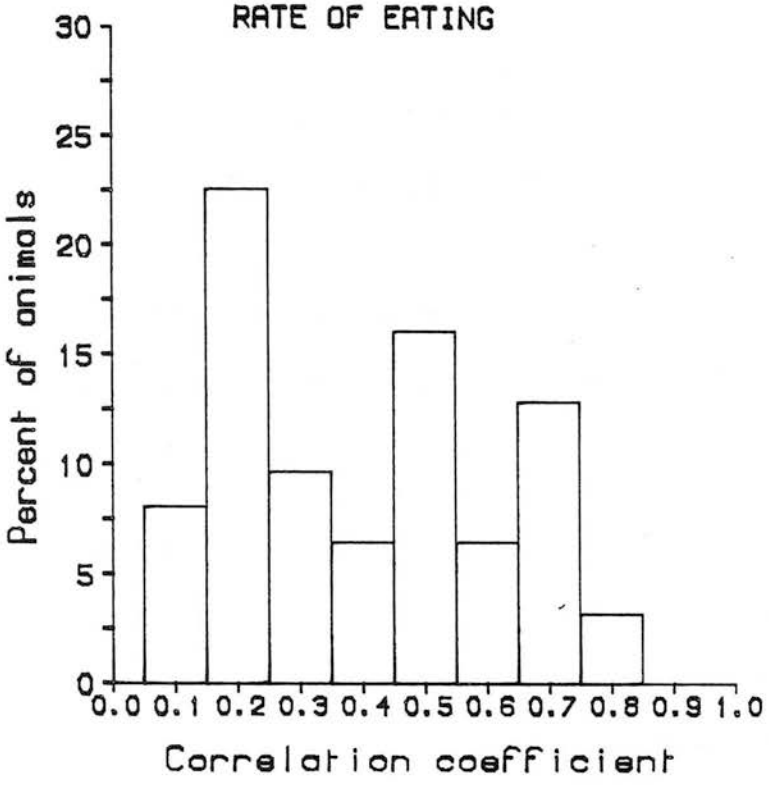
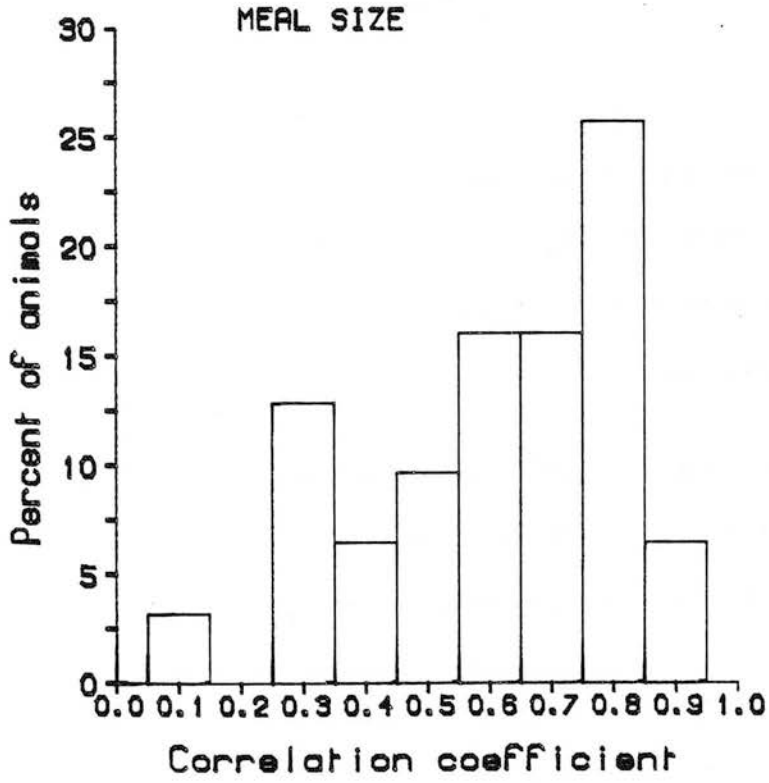


Figure 7.6 : Frequency distribution of correlation coefficients of drymatter intake with rate of eating and meal size for Investigation 4





meals eaten, NDMI and DDMI were higher for parity 2 cows than other parities. These daily differences remained for the 8 weeks of the experiment (Appendix Table A.63).

As might be expected, time spent eating, meal size, duration of meals, NDMI and DDMI increased with advancing lactation (Appendix Table A.63). Surprisingly, however, the number of meals eaten significantly ($P < 0.01$) declined as lactation progressed. The proportion of TDMI eating during daytime was not significantly different between stages of lactation. Differences between stages of lactation in time spent eating was associated with differences in FCM yields and LW.

DDMI was significantly ($P < 0.01$) correlated with time spent eating ($r = 0.543$), meal size ($r = 0.696$) and number of meals eaten ($r = 0.475$) but not rate of eating. These relationships were especially strong within periods of day (Table 7.8). Periods showed considerable variation in regression coefficients of PDMI on eating traits (Appendix Table A.64). Within cow correlations of DDMI and other eating traits also showed considerable variation (Figures 7.5 and 7.6).

Correlation coefficients between animal characteristics (milk and FCM yields, LW, BS, wither height, heart girth and body length) and eating traits were generally small (Appendix Table A.65). Calving BS was, however, negatively associated ($P < 0.01$) with number of meals eaten ($r = -0.475$) and DDMI ($r = -0.456$) over lactation weeks 1-4.

Correlations between meal size and pre- and post-meal intervals surrounding it were low ($r = +0.048$ and -0.197 respectively) and not significant. Similarly, the correlations between meal durations and pre- and post-meal intervals surrounding it were non-significant ($r = +0.069$ and -0.210).

7.3 Discussion

7.3.1 GENERAL

In this study it must be remembered that observations were not carried out over the full 24 hours, and, although a smaller proportion of feed (30-40% of TDMI) was consumed at night, the data are not totally complete. Furthermore, in Investigations 1, 2 and 3 eating behaviour observations were confounded with effects of stage of lactation, thus making it impossible to fully appraise this important relationship. Nevertheless, this does not render the observations of inter-relationships between eating traits and VFI less useful since most management of housed dairy cattle is concentrated in daytime hours. Also, any attempt at manipulating feeding arrangements to improve VFI would normally be initiated in daytime when the greatest amount of eating occurs (Vasilatos and Wangsness, 1980; Tanida et al, 1984).

In most experiments on the eating behaviour of dairy cattle no definition of minimum inter-meal interval is provided (Dulphy et al, 1980; Harb and Campling, 1983; Tanida et al, 1984). This lack of definition of minimum inter-meal interval makes it difficult to compare critically results of different experiments since the definition of minimum inter-meal interval governs the frequency of meals eaten. The 20-25 min minimum inter-meal interval obtained in this study is similar to 20 min obtained by Metz (1975) for dry non-pregnant cows and used by Vasilatos and Wangsness (1980) in their experiment. The possibility that animals may have varied in this minimum interval (Metz, 1975) could not be tested for lack of sufficient data.

The 3.4-4.9 meals eaten, 94.3-121.9 min spent eating and 2.12-2.9 kg DM

(13.7-19.5% of TDMI) per meal eaten cannot be compared directly with observations from experiments recorded over 24 h. Also, it would be erroneous to extrapolate these data to cover 24 h since eating patterns are not similar for day and night times (Metz, 1975; Vasilatos and Wangsness, 1980; Tanida et al, 1984). It has, however, previously been reported that cows producing daily about 30 kg milk in early lactation spent 253-280 min per 24 h eating 10.5-12.1 meals each averaging 3.6 kg as fed (8.7% total daily intake) (Vasilatos and Wangsness, 1980; Tanida et al, 1984) whereas lactating and dry cows were observed to spend 180 min per 24 h eating 10 meals of silage supplemented with 2-4 kg barley (Harb and Campling, 1983). From the results of Vasilatos and Wangsness the cows actually spent 96.3 min per 12 h eating. As previously discussed, the number of meals eaten depends on the definition given to a meal. Furthermore, the number of meals eaten can be influenced by the composition of the diet (Heinrichs et al, 1982; Harb and Campling, 1983; also discussed in Chapter 1.1.3.6).

There are few reports in the literature on mean inter-meal intervals. This is probably because of the arbitrary way most researchers chose their minimum inter-meal interval. However, Vasilatos and Wangsness (1980) reported a mean meal interval of 90.2 min. In the present study this ranged from 118-176 min. Differences between the studies were undoubtedly due to differences in management and length of recording. For example, a major effect of allowing animals the opportunity to go outside voluntarily for exercise was to increase the first inter-meal interval (from 99.8 min in Investigation 1 to 148.7 and 218 min in Investigations 2 and 3 respectively) and mean inter-meal intervals. A striking result in this study was the similarity between first inter-meal

interval and mean inter-meal intervals in early lactation (122.0 vs 128.2 min). This suggests that cows tended to eat more regularly in early than middle lactation (Investigation 1) either because of high nutrient requirement at this time (Bines, 1979) or because of differences in composition of the diet (Appendix Table A.66).

The noticeable aspect of the present results was, also, the similarity in Investigations 2, 3 and 4 in the proportion of TDMI eaten during the day, even though management and stage of lactation were different. This would tend to suggest that under different management and physiological states these animals endeavour to eat a constant proportion of TDMI in the day. This is in line with previous reported work that most eating activity of housed dairy cattle occur during daytime hours (Vasilatos and Wangsness, 1980; Tanida et al, 1984). This is probably related to time budgets of eating and ruminating. Most rumination occurs at night (Metz, 1975; Harb and Campling, 1985).

7.3.2 PATTERNS OF EATING BEHAVIOUR

There was a high degree of similarity in the eating patterns of the cows in the four investigations. Under complete confinement (Investigations 1 and 4) cattle were noted to have two main peaks of eating activity, 1 h after feeding, even though feed was available all the time, and during the h after milking, during which time most animals ate. Similar patterns of eating behaviour have previously been observed for housed lactating dairy cattle (Vasilatos and Wangsness, 1980; Little and Harrison, 1984; Tanida et al, 1984). As suggested by Tanida et al (1984), feeding and milking times might act as effective stimuli for increased eating activity patterns. This could be due to several causes:

(1) Social facilitation especially after feeding (Hsiah and Woodgush, 1983) and milking.

(2) Visual, gustatory or olfactory cues during first feed offering (Baile, 1975).

One could also speculate that the rate of utilization of nutrients and amount of nutrients required for milk synthesis probably declines as the time between milkings increases causing a change in the motivation to eat.

The high repeatability of this pattern of eating suggests that cattle divide the day into periods of eating and non-eating activity. For complete confined animals, the period following offering of fresh feed tended to be the most important period in time spent eating, in number of meals eaten and PDMI. It is interesting that there was lack of uniformity in the relationships between PDMI and eating traits across periods (Appendix Table A.64). Most regression coefficients of PDMI on eating traits were higher in the periods following on feeding and milking. These results therefore suggest that pooling data for a whole day, as is done in the literature, can give misleading relationships which might differ in strength and sign from those observed in homogenous periods (Metz, 1975).

It would seem, however, that this repeatable pattern of eating behaviour can be modified. In Investigations 2 and 3 allowing 2.5 and 4.0 h of voluntary non-confinement resulted in a third peak of eating activity which occurred within 1 h after the end of non-confinement. The height of this peak was positively related to the period of non-confinement, although most animals ate within this hour. One interesting aspect of the present results was the preference of the animals for going outside the barn than continuing to eat, even when they had just started to eat. Why

few animals also returned to eat during the period outdoors is not clear. These results, however, raise some questions of animal welfare. Perhaps the constant urination and defaecation by animals confined inside the building over a long period had provided an unpleasant environment, so that cows preferred to stay outside rather than return indoors to eat. One could also speculate that the animals were in need of vitamin D (Schmidt and Van Vleck, 1974). The two investigations occurred in the summer when the sun shone.

These results tend to indicate that the period of exercise had no detrimental effect on TDMI. This is supported by lack of difference in TDMI between Investigations 1 and 3. Furthermore, TDMI in the week prior to the commencement and during Investigation 2 were similar (13.3 vs 13.1 kg). It appears that these animals adapted to the pattern of management not by eating more at night, but by eating more in the immediate period after the end of exercise. Furthermore, in Investigation 2 the animals adjusted to the change of management by eating faster before the beginning of the exercise period, thus keeping feed intake in Period 1 almost constant. The rate of eating and PDMI in Period 1 in the week prior to commencement and during the investigation were 0.48 and 2.85 and 0.52 kg/5 min and 2.99 kg respectively. These results also tend to suggest that dairy cattle have the ability to learn and adjust to previous experience.

These animals were fed high quality feed. It would therefore be interesting to know what the effect of this pattern of eating on VFI and milk yield of animals fed low quality feed would be. This probably may not be important in middle and late lactation but might result in depressed VFI and milk yield in early lactation. For example, observations with high

yielding cows fed good quality feed but allowed voluntary exercise showed depressed milk yields in early lactation (E M Bell, Personal Communications). Nevertheless, these results do indicate that animals confined prefer some outside environment to normal pattern of eating indoors. However, some properly designed choice experiments are required to evaluate the importance of outdoors for the welfare of the animals and for milk production. But, as pointed out by Dawkins (1980), choice tests are difficult to evaluate especially in respect of animal welfare because animals do not always choose what is best for their physical health in the long run.

The current results question the provision of 100% feeding trough space for all animals to eat simultaneously under ad libitum feeding conditions; for at the height of most eating activity not more than 90% of animals ate. This could have been partially due to non-competitive situation; animals had individual feeding spaces. Also the habit of some animals to stand blocking the feeding trough space of some other animal could explain some of this pattern of space usage. Reports from group feeding of dairy cattle indicate that more submissive cows ate after more dominant cows (Harb et al, 1985). Presumably this effect of social behaviour was involved in the conclusion of Coppock et al (1981) that housed group fed dairy cows under ad libitum feeding did not require 100% feeding trough space.

In agreement with previous reports (Burt, 1957), this study has shown that cows ate faster and heavier meals than heifers of similar milk yields and LW. In early lactation, cows were also noted to spend a longer time eating more meals and DM than heifers of similar FCM yields and LW. These results are similar to the observations of Tanida et al (1984) who

found a linear influence of parity on total time spent eating. Reticulo-rumen capacity rather than LW could explain differences between parities in meal size and DDMI (Nutt et al, 1980). Also, the larger oral cavity of cows than heifers could help to explain parity differences in rate of eating. It has, however, been reported that younger animals spend more time masticating feed than older cows and this affects rate of eating (Campling and Morgan, 1981). These results, however, do suggest that under limited time of access to feed heifers will be more at a disadvantage in VFI than cows.

Appetite increases gradually after calving reaching a peak in weeks 12-16 of lactatin (Bines, 1979). It would be expected that most eating traits would increase as lactation progressed towards peak appetite. In support of this expectation time spent eating (though not significant), meal durations and meal size increased with advancing lactation. The noticeable aspect of the current results was animals ate more meals in lactation weeks 1-4 than weeks 5-8 and this resulted in shorter intervals between meals at this time (weeks 1-4). These results are contrary to some reports in the literature. Burt (1957) could not demonstrate the influence of stage of lactation on rate of eating; Little and Harrison (1984) observed no influence of stage of lactation on time spent eating silage whereas Tanida et al (1984) could find neither linear nor quadratic effect of days of lactation on any eating trait. However, Journet and Remond (1976) noted that time spent eating increased by almost 90 min from day 30-60 of lactation while rate of eating declined. Differences between experiments could be related to differences in diets fed and methods of measurement (Dulphy et al, 1980; Campling and Morgan, 1981). It has especially been noted that cows tend to eat more meals in

early lactation when concentrate:forage ratio is high than later in lactation when this is low (Little and Harrison, 1984). There was no change in diet between the two stages of lactation in this study. Social interactions of mounting and other antagonistic behaviour which were noted to be high in early lactation were probably responsible for more meals eaten at this time. This would be expected to disrupt the normal eating patterns of animals. One could also speculate that physical limitations of the gut, due to abdominal fat, (Bines, 1976) prevented the animals from eating more feed per meal at this time. The negative correlation of calving BS and number of meals eaten at this time ($r = -0.475$) tends to discredit this argument.

One question of interest is whether certain eating behavioural vaiables are unique for individual cows or consistent among animals. The results showed large variations in eating traits between animals within parities which were not associated with LW or milk yield. These results do not support observations of Vasilatos and Wangsness (1980) that meal size and rate of eating were consistent among cows whereas number of meals eaten and meal durations were unique for individual cows. The differences between the two experiments and between animals in this study could be related to number of animals observed and to the method of recording eating behavioural traits. Vasilatos and Wangsness (1980) used only 5 animals and this probably resulted in less variation in some traits observed. Also, in the present study, some animals tended to spend time shifting the feed in the bin before eating. This individualistic behaviour of animals is borne out by large variations in within cow correlations of DDMI on eating traits (Figures 7.5 and 7.6). This inter-individual variation, if consistent over 24 h of observations, would make

it difficult to construct individual eating behavioural prediction models.

7.3.3 RELATIONSHIPS BETWEEN ANIMAL CHARACTERISTICS AND EATING TRAITS

The current investigation tends generally to support the view that variation in VFI within a period of time depends on

(1) number of meals eaten in that period;

(2) duration of meals;

(3) rate of eating;

(4) meal size (Bines, 1976).

Time spent eating and meal size were noted, in all investigations, to have a greater influence on VFI than other eating traits. The influence of meal size on VFI probably reflects the way in which cattle attempt to consume sufficient feed to meet energy requirements especially in early lactation. This is borne out by significant correlations between LW and meal size ($r = 0.479$) and milk or FCM yields and meal size ($r = +0.517 - +0.603$).

Rate of eating was only an important factor influencing VFI in middle and late lactation while number of meals eaten was important under conditions of a self-inflicted long period of fasting as in Investigation 3 ($r = 0.690$). Under restricted feeding or limited access to feed and in group feeding situations where there is competition, it would be expected that rate of eating would be an important factor influencing feed intake (Harb and Campling, 1983; Harb et al, 1985). In Investigations 2 and 3 it can be assumed that since these animals spent a long time before eating they were probably hungry when brought in and this resulted in the significant association between DDMI and rate of eating. The results of Investigation 1 are difficult to interpret.

Bines (1976) argued that for improved feed intake all the eating variables (number of meals eaten, meal size, duration of meals and rate of eating) must be increased without a proportional decline in the others. The negative correlations between number of meals eaten and meal size (r = -0.292 to -0.522) and rate of eating and time spent eating (r = -0.554 to -0.635) (Appendix Table A.64) indicate that it may not be possible to change one of these variables without a concomitant negative change in the others. This would tend to suggest that periods of non-eating activity are not amenable to manipulation for improved feed intake. This is further evidenced by the results of Coppock et al (1981) who noted that frequent feeding resulted in more meals eaten but a decline in meal durations and thus no increase in TDMI.

Cattle also appear to prefer light to darkness during eating (Tanida et al, 1984). The use of night lighting in the feeding area would be expected to improve VFI. The low correlations between DDMI and NDMI in early lactation would tend to agree that there is room for improved feed intake by night lighting or by providing fresh feed at dusk. However, the lack of difference in time spent eating observed for cows on 24 h and 18 h light regimes (Tanida et al, 1984) cast doubt if basic time budgets for eating, ruminating and idling can only be manipulated by this method.

There was generally lack of relationship between eating traits, except meal size, and milk yield or LW in the current study. Many authors have reported lack of association between these varibles (Dulphy et al, 1980; Tanida et al, 1984; Harb et al, 1985). This is in contrast to the results of Burt (1957) who found that 40% of the variation in the rate of eating hay was associated with LW. These results would tend to disagree with the computer model of Forbes (1983) that eating traits, as number of

meals eaten, are positively associated with energy requirements. While this may be so for DDMI it would appear that this relationship is more complex than this simplistic view. This could be due to:

(1) large between and within cow variations in these relationships;

(2) error in recording behaviour traits due to individuality of animals previously discussed;

(3) length of the recording period (as in current study).

Baumgardt (1970) suggested that signals for long-term control of VFI may be related to body fat stores and this involves correcting errors in individual meals over a long period of time. Short-term control of VFI, on the other hand, is controlled by feed back signals produced by gut fill and digestion and metabolism following consumption of a meal. The lack of significant correlation between meal size and calving BS ($r = -0.212$) but a significant negative correlation between calving BS and DDMI ($r = -0.465$) would tend to support this long-term regulation of VFI.

Information on the underlying mechanisms involved in the short-term control of meal eating can be obtained by calculating correlation coefficients between meal size and meal intervals surrounding it (Metz, 1975; Chase et al, 1976; see Chapter 1.1.3.6 for details). If meal size is positively correlated with length of the preceding interval, this implies that there is a satiety mechanism. Conversely, if meal size is positively correlated with the length of succeeding interval this implies a hunger mechanism. Significant pre-prandial correlations have been observed for dry dairy cattle (Metz, 1975) suggesting the presence of a satiety mechanism. In the current work weak but significant correlations between meal size and pre-meal intervals were observed in Investigations 1, 2 and 3. These low correlations were presumably due to the pooling

of data across different periods of the day to provide sufficient number of observations. It could also be due to inadequacies in the criteria used for defining meals. The present results, however, suggest that under ad libitum feeding in middle and late lactation, meals tend to stop once some fixed level of feed repletion is reached, rather than start when feed ingested in last meal is used up. It is difficult to speculate on the physiological mechanism behind the control of meal eating in this study.

Since the animals were fed good quality feed physical regulation of intake (Campling, 1970) would be expected not to play an important role in meal eating here. It is also unlikely that changing levels of metabolites in the blood or the production of VFA could be involved in termination of meals. VFA levels are reported to be almost constant under ad libitum feeding (Baile and Della-Ferra, 1981). Furthermore, there does not seem to be enough time for meals to be digested and absorbed during a meal. One could speculate that termination of a meal originates from the meal itself, due to an urge to ruminate. Reports indicate that periods of rumination are linearly related to amount of feed intake and coarseness of feed particles (Metz, 1975).

7.4 Conclusion

The results demonstrated that housed lactating dairy cattle have a diurnal pattern of eating with major peaks of eating activity occurring within 1 h after fresh feed offering and milking during which most animals ate (maximum 90%). This repeatable pattern can be modified by management. Allowing cows voluntary exercise outside the barn resulted in a third peak of eating activity 1 h after the end of exercise because few animals returned to eat during the exercise period, although they were at liberty to do so. Animals tended to

adjust to the period of execise by eating faster before the exercise or eating more after the exercise. The exercise period had therefore no detrimental effect on proportion of TDMI eaten in the day.

Partitioning the day into periods following on the eating patterns showed that periods differed in all eating traits with high values occurring in the immediate periods after feeding, milking and returning from exercise paddock. Periods also lacked homogeneity in the relationships between PDMI and eating traits, The highest regression coefficients of PDMI on eating traits occurred in the periods following on peaks of eating activity.

There were no differences between the eating patterns of cows and heifers in the day. However, cows tended to eat faster and heavier meals than heifers, suggesting that under limited access to feed, heifers will be at a disadvantage in VFI than cows. There was a lack of similarity in the relationships between DDMI and eating traits between animals.

As was anticipated, all eating traits except number of meals eaten increased as lactation progressed. Differences between stages of lactation in eating traits were associated with differences in LW and FCM yield.

Meal size and time spent eating were the most important eating traits influencing DDMI accounting for 50% of the variation. Rate of eating and number of meals eaten tended to be important factors on DDMI under conditions of a long period of non-eating activity (> 2.5 h).

Correlation coefficients between meal size and number of meals eaten were significant and negative. Correlations between meal size and the intervals surrounding it were generally small. There were no strong correlations between eating traits and LW and milk yield except meal size.

In conclusion:

Fresh feed offering and milking serve as stimuli for increased eating activity of cows and heifers under confinement. Periods of the day need to be considered in the analysis or evaluation of eating traits to prevent bias. Cows confined for a long period have preference for outdoor exercise over normal eating activity indoors. Properly designed choice experiments covering 24 h and in different stages of lactation are required to evaluate this phenomenon on milk production and animal welfare. The constant proportions of TDMI eating in the day and the negative correlations between eating traits put limitations on manipulation of VFI through eating behaviour. Inherent differences between animals in time spent eating and meal size are partially responsible for animal variation in VFI. The lack of similarity between animals in the relationships between DDMI and eating traits suggest difficulties in the building of an individual cow model of eating behaviour. More evidence from experiments covering 24 h is required in support of this suggestion. Hunger and satiety mechanisms cannot be unequivocally demonstrated under the conditions of this study.

8 GENERAL DISCUSSION

Voluntary feed intake in early lactation is a major constraint to the milk production of high yielding dairy cows (Balch, 1976). Research has therefore been concentrated upon the physiological, managerial and nutritional factors which could improve VFI (Baile and Forbes, 1974). Recommendations from these experiments have resulted in improved feed intakes of cows through:

(a) Frequent feeding of concentrate (Kaufman, 1976).

(b) The use of higher energy diets fed ad libitum as a complete mix (Coppock et al, 1974; Phipps et al, 1984a).

(c) The use of mineral buffers etc (see Clark and Davis, 1983).

It is now important to discover whether VFI can further be improved by other means.

Many characteristics of the animal are known to interact with nutritional and managerial factors to influence VFI (Bines, 1976, 1979; Broster et al, 1982). These interacting factors have been used in the prediction of VFI (see Table 1.4, Chapter 1) and also in computer simulation of appetite (Forbes, 1977, 1983). These prediction equations have only accounted for 76% of the total variation in DMI. Thus, based on these factors, DMI of individual cows on ad libitum forage, but different levels of concentrate feeding, can be predicted for individual cows to within ±1.6 kg and for groups of cows to within ±1.1 kg (Vadiveloo and Holmes, 1979). These equations have all been retrospective rather than predictive. Furthermore, there is a tendency to believe that a significant relationship between two measured factors somehow explains the cause of that relationship (Whittemore, 1981). Also, many experimental data have been obtained with animals of relative low milk yield (< 5000 kg), or with animals fed according to milk yield, resulting in

confounding of effects between milk yield and VFI (Korver, 1982). The use of these factors immediately post-partum will therefore be more predictive and be meaningful in a biological or productive context. Moreover, to improve the precision of predictions of VFI, more information is required on the effects of these factors on VFI during different stages of lactation.

There is little experimental evidence on the influence of animal characteristics on VFI, especially immediately post-partum, unconfounded by other factors. The objective of the present project was to provide from the bank of data such information not only for VFI but also nutrient utilization for milk production of high yielding (> 6500 kg) cows. To this end animals were allowed to express their genetic potential for VFI and thus milk production by feeding ad libitum a complete diet mix of forage and concentrate high in energy concentration and adequate in protein, minerals and vitamins (ARC, 1980). Also the influence of calving LW, calving BS, LWC and milk yield in lactation week 2 (unconfounded by environmental and other factors, years and months of calving and parity) were included in the analysis of variance models.

The range of total variation explained by these factors on DMI, energy balance, milk yield in subsequent stages of lactation and gross, net and nitrogen efficiencies are shown in Table 8.1 (see also Chapters 3, 4 and 5). Also, the variation explained by average LW, MY, BS and LWC in the period of lactation on these same variables are also indicated in Table 8.1 (see Appendix Chapter 4).

The influence of these factors generally declined as lactation progressed. This was especially marked for BS and LWC. Both sets of analysis showed that a large part of the variation in these traits could not be explained by these factors even though they are are the main requirements for energy

Table 8.1 Range of total variation (R^2%) accounted for by animal and environmental factors in DMI, nutrient utilization and milk yield for Trials 1 and 2

	TRIAL			
	1		2	
TRAITS	**Factors immediately post-partum**	**Factors* during lactation**	**Factors immediately post-partum**	**Factors** during lactation**
Dry matter intake	41.3-60.1	43.1-62.6	48.0-74.9	52.7-70.7
Energy balance	30.1-69.0	42.5-71.0	28.6-50.6	29.7-54.5
Gross efficiency	25.5-69.0	55.1-73.3	35.5-62.2	57.8-77.4
Net efficiency	27.5-68.0	32.7-55.2	32.6-42.9	39.0-61.3
Nitrogen efficiency	19.3-48.1	38.5-65.2	20.8-58.9	34.8-59.9
Milk yield	23.3-59.9	-	33.3-91.5	-

* Excludes year and month of calving and parity

** Excludes month of calving and parity

expenditure within the animal. It is interesting to note the similarity in the proportion of variation explained by these factors in both VFI and energy utilization traits. This suggests that variation in VFI has more effect on the variation in energy utilization or vice versa than milk yield. Coppock et al (1974) and Bieri et al (1982) also observed that animal characteristics accounted for a maximum of 61-68% of the variation in VFI.

In Chapter 3.1.2 it was argued that this relationship of the factors with VFI and nutrient utilization could be attributed to:

(a) Lack of fit of the models, that is the factors are not linear or quadratically related to these variables.

(b) Large errors of measurement.

(c) The coefficients are not constant across the range of animals. Also the nutrient resource may not equally affect all cows.

The following results from this thesis, together with personal observations,

lend credence to these arguments:

(a) In Chapter 6, LWC calculated within periods was observed not to be related to the corresponding LW within some periods when logic suggests that they should have been closely correlated.

(b) LW measured in the morning and afternoon for the same cow differed by a maximum of 12 kg (Appendix Chapter 3), this can markedly influence calculated LWC.

(c) The body condition scoring system adopted (even assessing to 0.25 condition score grades) does not provide a sufficiently sensitive measure of body fat reserves to enable relationships to be detected for animals differing slightly in body fatness (see Appendix Chapter 3).

(d) Some animals tend to drop feed from their mouths into the dung as a result of inefficient prehension. This "lost" feed can result in substantial errors in DMI and ME intake estimates.

(e) Due to froth on top of milk in milk jars, operator error in reading the height in the jars could be +0.5-1.0 kg/milking.

From the foregoing, it would appear that until these errors in measurement of DMI and animal characteristics are reduced multiple regression techniques for the simulation of VFI will continue to be relatively imprecise. The current results also suggest that future VFI predictions must take account of differences between stages of lactation, by the use of stage of lactation constants or the generation of individual stage of lactation equations. Also, the inclusion of a genetic component in prediction equations could improve the precision of predictions (Vadiveloo and Holmes, 1979). Studies on genetic differences between animals of similar LW, MY and BS fed ad libitum are required. Previous work suggests that heritabilities of forage and total net energy intake in cows given forage ad libitum and concentrate according to

milk yield were 0.19 and 0.42 (Miller et al, 1972), but no data exist for ad libitum complete diet fed animals.

With increasing understanding of the influence of these factors, it is possible that a greater precision can be achieved in predicting cow responses in early lactation. This can be attained by arranging the nutrition and management of animals so that they calve at pre-determined levels of factors such as BS. The effects of these factors on production traits are further discussed in the following section.

The problem of how to feed high yielding dairy cows to achieve energy equilibrium very early in lactation has proved intractable. Milk production generally increases faster than feed intake in the first 50 days of lactation, resulting in underfeeding and body tissue mobilization by high yielding cows (Journet and Remond, 1976; Bines, 1976, 1979). Generally, it appears that energy rather than protein requirements are difficult to meet (Broster and Alderman, 1977). However, these authors came to the conclusion that feeding of high yielding cows did not require extravagant allowances of feeds as milk yields in the order of 40-50 kg/day can be obtained with 4-5 kg concentrate/10 kg milk yield. Clark and Davis (1983) noted that cows that have the ability to consume DM in excess of 3.5% of LW have a particular capacity for high milk yields. Thus to reduce energy deficit and yet avoid metabolic disturbances, such as acidosis, the roughage must be supplemented with concentrate to supply up to 75% of the total diet (Broster et al, 1982). Maximum DMI was achieved when the concentrate component was 55-60% of the diet (Clark and Davis, 1983). This approach resulted in reducing, but not completely removing, the lag between feed intake and feed requirements (Coppock et al, 1974; Phipps et al, 1984b). Addition of protected fat to the diet has also been partially effective in achieving a reduction in the energy

gap (Bines and Hart, 1982). Thus under the best feeding conditions, based upon current knowledge, cows producing over 35 kg FCM/day will mobilize about 50 kg body lipid in the first 10 weeks of lactation, equivalent to 9 kg FCM per day (Bauman and Curie, 1980). The consequence is an inverse relationship between milk yield and LWC which is more marked in high yielding cows (Broster, 1976).

The ability of the high yielding dairy cow to use body reserves in early lactation was demonstrated in Chapter 5.2.2.4 of this thesis. In addition, cows producing a peak yield of 40 kg/day catabolized as much as 50 MJ ME/day in lactation weeks 2-6 and lost 0.49 units BS and 1.9 kg/day LW from calving to lactation week 24 even though they consumed 24.1 kg DM/day (280 MJ ME) at peak intake (Table 8.2). These results have therefore shown unequivocally that the high yielding dairy cow produces more milk, has greater appetite and generally tends to use more body reserves early in lactation than low yielding animals (Figures 8.1, 8.2, 8.3 and 8.4). The high yielding dairy cow is still more efficient than the low yielding animal. Maintenance requirement forms a small proportion of milk energy requirement (correlation between 305-day FCM and gross efficiency in lactation weeks 2-24 was 0.592 for cows and 0.742 for heifers). It would therefore appear that the physiological response to selection for milk yield is a complex genetic mechanism for maximising the amount and availability of catabolizable adipose tissue at calving for cows but not heifers (Bauman et al, 1985). This was previously shown for cow Lorna discussed in Chapter 5.2.2.4 (Flatt et al, 1969). There is, however, the problem as to whether it is the amount of mobilizable fat that facilitates high yield or whether it is high yield that requires mobilization of body fat. The lack of significant association between calving BS and milk yield would tend to suggest that high milk yield causes the mobilization of body fat. However,

Table 8.2 Production characteristics of some very high yielding cows and heifers

TRAIT	COWS		HEIFERS
	Mean	SD	Mean
Number of animals	18		4
Peak milk yield (kg/day)	44.5	3.17	29.3
Week of peak yield	5.9	2.37	7.0
DMI intake at peak yield (kg/day)	20.7	2.96	19.3
ME intake at peak yield (MJ/day)	243	34.4	225
Maximum DMI (kg/day)	24.1	2.22	20.8
Maximum ME intake (MJ/day)	281	25.9	240
Week of maximum DMI	10.9	4.21	15.3
Energy balance - week 2-6 (MJ ME/day)	-57.7	33.2	11.2
305-day FCM yield (kg)	8951	1167	9064
305-day milk yield (kg)	8638	840	7333
Calving liveweight (kg)	694	73	521
Calving condition score (1-5 units)	3.35	0.92	2.69
Condition score change - weeks 0-24	-0.46	0.61	-0.19
Weight change - weeks 0-24 (kg/day)	-1.9	1.00	4.6
Milk fat content at peak yield (g/kg)	42.0	6.21	47.1
Milk protein content at peak yield (g/kg)	33.3	4.09	30.8
Gross efficiency - weeks 2-24 (%)	47.2	4.29	42.3
Net efficiency - weeks 2-24 (%)	63.1	6.62	55.0
Rate of milk yield decline from peak to week 24 (%/week)	2.29	0.42	0.73

Figure 8.1 : Relationship between energy balance(Y,MJ ME/day) over lactation weeks 2 to 6 and 305-day FCM(X,kg) for different years of experiment Years 1(X),2(*),3(O) and 4(-) Y=28.1(SE,17.9)-0.0068(SE,0.0023)X, R^2=6.3%,RSD=34.0

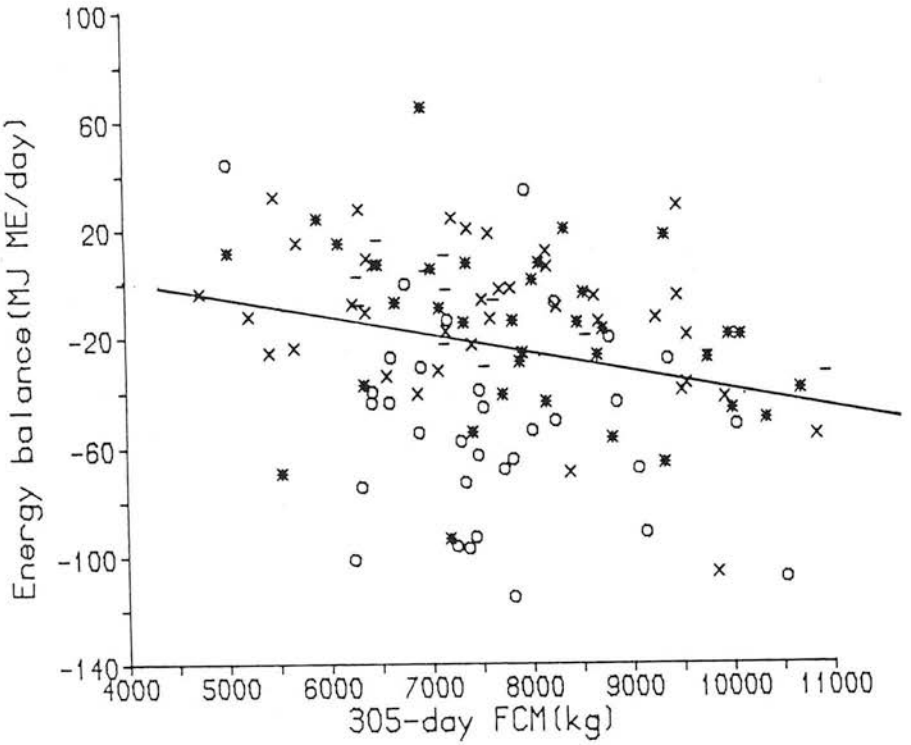


Figure 8.2 : Relationship between energy balance(Y,MJ ME/day) over lactation weeks 2 to 6 and 305-day FCM(X,kg) for different heifer groups of experiment: Years 4(x) and 5(*) Y=29.7(SE,18.2)-0.00314(SE,0.00261)X, R^2=0.9%,RSD=21.8

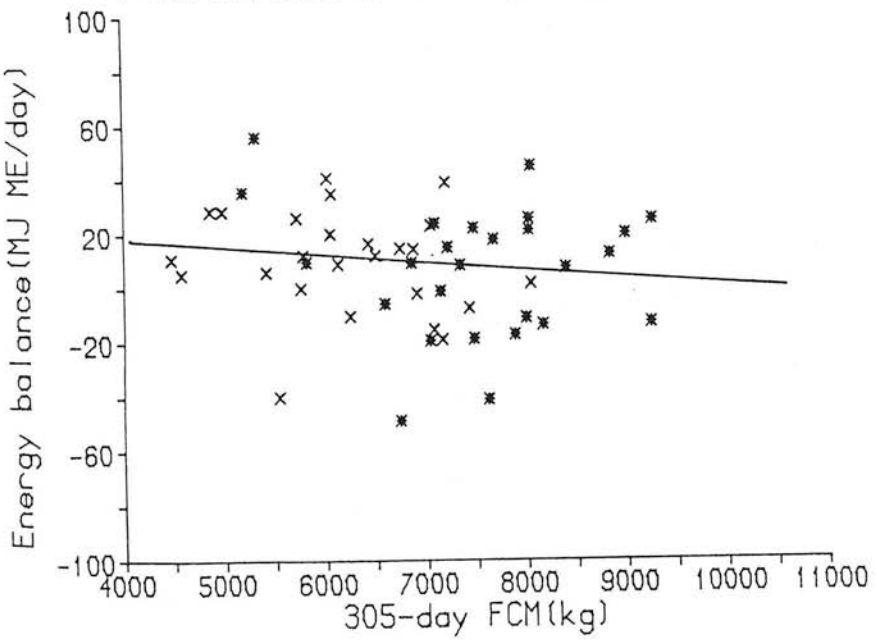


Figure 8.3 : Relationship between energy intake(Y,MJ ME/day) over lactation weeks 2 to 24 and 305-day FCM(X,kg) for different years of experiment :Years 1(X),2(*),3(O) and 4(-) Y=162.3(SE,11.1)+0.0076(SE,0.0014) R^2=19.4%,RSD=21.1

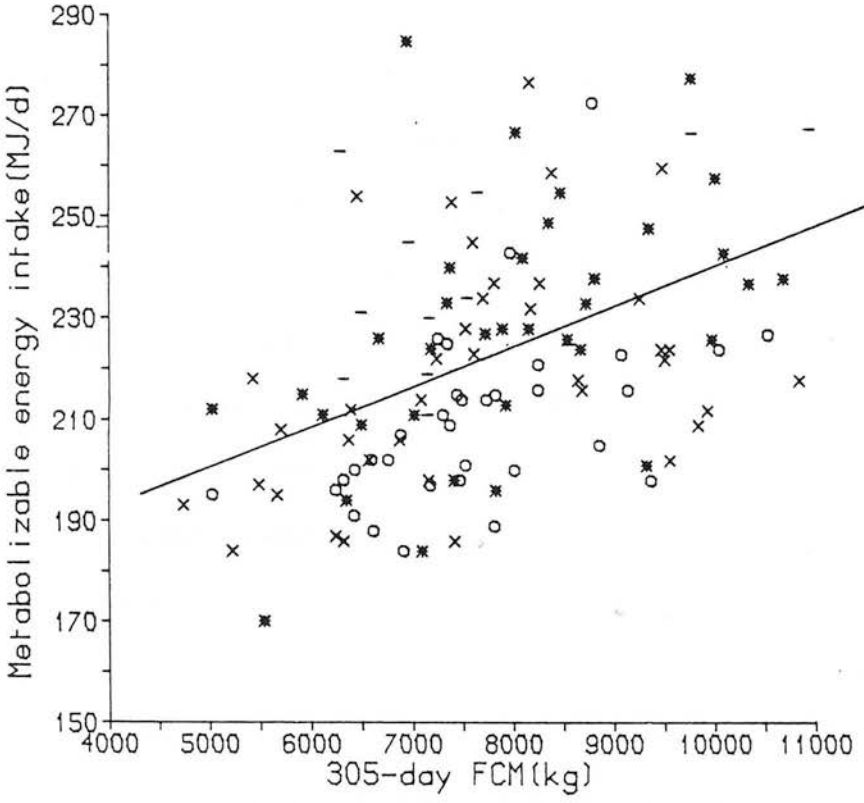
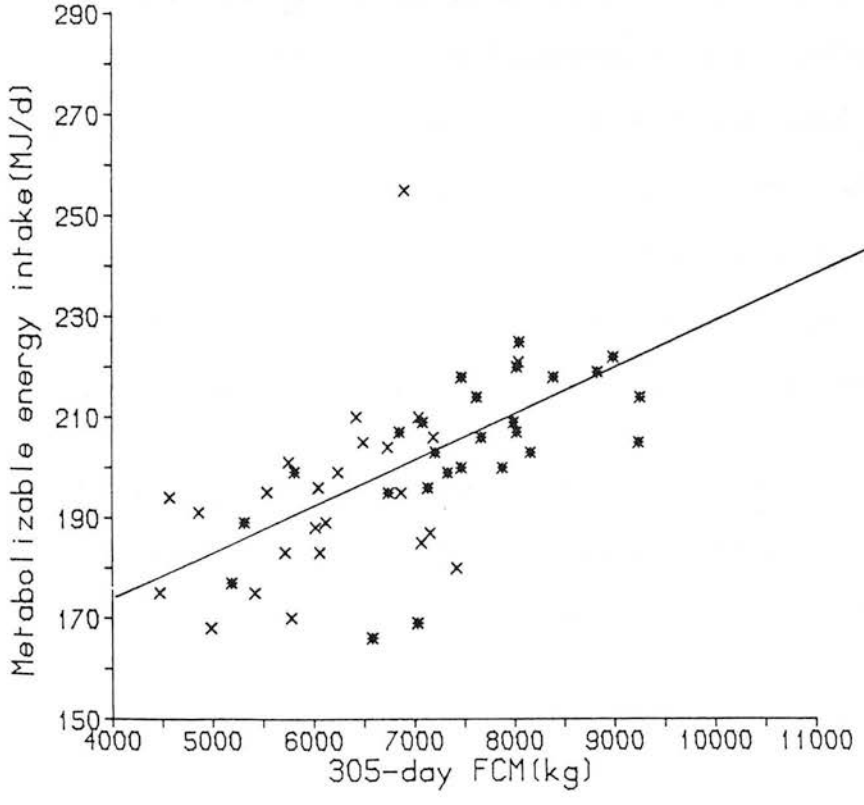


Figure 8.4 : Relationship between energy intake(Y,MJ ME/day) over lactation weeks 2 to 24 and 305-day FCM(X,kg) for different heifer groups of experiment :Years 4(X),5(*) Y=139.6(SE,11.6)+0.0087(SE,0.0017)X, R^2=34.3,RSD=13.9



as discussed in Chapter 5.2.2.3, an answer to this dilemma cannot be deduced from the current study; because most animals were in relatively good condition. Furthermore, as shown in Figures 8.1 and 8.2, individual animals differ in the extent to which fat reserves are utilized in lactation. This suggests that variation exists amongst animals (eg between cows and heifers) in the control mechanisms of body fat mobilization. Only 35.3% of heifers (but 80% of cows) were in negative energy balance in lactation weeks 2-6. Also, of 4 heifers producing 9,000 kg FCM in 305 days only one was calculated to be in negative energy balance. There may be two reasons for differences between cows and heifers:

(a) Lower body reserves of heifers at calving (Miller et al, 1969).

(b) Lack of physiological adaptation by heifers to mobilize body fat.

Perhaps part of the higher persistency (Broster and Broster, 1984) and the higher correlation between gross efficiency and 305-day FCM yield for heifers than cows is because heifers catabolize less body fat to produce more milk at and prior to the establishment of peak yield. This is also in line with the hypothesis that cows which mobilize large quantities of body fat for milk energy production have a change in food partition towards body gain than milk energy later in lactation. This hypothesis is given further credence by the increasing correlations between 305-day FCM and milk yields and milk fat content as lactation progressed. (For FCM, r = 0.088, 0.407, 0.515, 0.613 and milk yield, r = 0.041, 0.260, 0.366, 0.438 for lactation stages 1, 2, 3 and 4 respectively). This further supports the argument that the most efficient animal is one with minimum LW change during lactation (Broster, 1974).

From the foregoing it would appear that negative energy balance of the high yielding cow in early lactation is inevitable under different feeding and management systems. The detrimental effects of high negative energy

balance on health and reproduction of cows is acknowledged (Haresign, 1982). From the performance of genetically superior cows, such as Beecher Arlinda Allen (25, 300 kg/365 days of lactation) and Maple Grand Rockman Meadow (24, 152 kg/360 days of lactation), it is apparent that dairy cows are able to achieve substantially greater levels of milk production without suffering health and reproductive problems (Clark and Davis, 1983; Bauman et al, 1985). Beecher Arlinda Allen consumed 26 kg hay and 25 kg concentrate (6.6% of LW). Furthermore, of 25 cows and 10 heifers producing, on average, 9814 and 8488 kg FCM in 305 days respectively in the current study, few exhibited disease or reproductive problems. The calving interval averaged 398.5 (SD = 52.3) and 434.6 (SD = 45.9) respectively. Three cows and one heifer were culled for reproductive problems. On average, the incidence of disease was 1.2 occasions/cow and 0.6 occasions/heifer over the 24-week lactation period. There were only 3 cases of acetonemia and 2 of milk fever recorded for cows. There were, however, 14 and 3 cases of lameness noted for cows and heifers respectively. It is also interesting to note that of the 4 cows in average negative energy balance of about 100 MJ ME/day discussed in Chapter 5.2.2.4 only one had acetonemia.

The current study further showed that high yielding cows do not suffer in subsequent lactations due to producing high milk yields.

The regression between 305-day FCM or milk yields (kg) in 2 consecutive lactations were (b±SE):

Cows (n = 30)

FCM (2nd year) = 4259 ± 1301 + 0.433* ± 0.178 FCM (1st year)

R^2 = 14.9%, RSD = 900.8

Milk yield (2nd year) = 3372 ± 1213 + 0.582 ± 0.156 milk yield (1st year)

R^2 = 31.7%, RSD = 1059.1

Heifers (n = 14)

FCM (2nd year) = 3353 ± 1777 + 0.613 ± 0.274 FCM (1st year)

R^2 = 23.6, RSD = 879.4

Milk yield (2nd year) = 4108 ± 1776 + 0.459 ± 0.284 Milk yield (1st year)

R^2 = 11.0, RSD = 785.6

Furthermore, although the trend was for high yielding cows to decline in calving BS in the succeeding lactation, LW or BS loss in the previous lactation had no significant influence on 305-day milk and FCM yields in the succeeding lactation. Correlations between BS loss and 305-day milk and FCM yield were 0.110 and 0.153 and between LW loss and these same traits was 0.249 and 0.305 respectively. The regression of calving BS in succeeding lactation on 305-day FCM yield (kg) in previous lactation was (b±SE):

Cows

BS = 5.643 ± 0.820 - 0.00028* ± 0.000105 FCM

R^2 = 17.9, RSD = 0.716

Heifers

BS = 3.236 ± 0.353 - 0.000977 ± 0.000543 FCM

R^2 = 14.6, RSD = 0.675

The adverse effect of negative energy balance may therefore be related to our definition of requirements. Optimisation of metabolic processes is to provide the proper amounts and balance of key nutrients for milk synthesis. Requirements or limiting nutrients may not be the same for all animals, especially in early lactation and may be related to body reserves at calving (Emmans and Neilson, 1984). Thus the limiting nutrient requirements of a fat animal may not be energy but some other nutrient. Kronfeld (1982) demonstrated that excess glucogenic and lipogenic nutrients in the diet was

the cause of spontaneous ketosis in cows fed adequate diets based on our present knowledge. Whitelaw et al (1985) showed that abomasal infusion of casein resulted in the correction of amino acid deficit with a concomitant increase in FCM, milk and protein yields. Body fat mobilization was of secondary importance. This suggests that the constituent amino acids may not have been acting by priming the tricarboxylic acid cycle to facilitate metabolism of 2-carbon which might allow or enhance mobilization of body fat as was first thought (Orskov et al, 1977). Considerable progress can therefore be made in our knowledge of milk production if the nutrient or metabolite requirements can be determined for individual animals.

The current hypothesis that feed intake of high yielding cows in early lactation is the major constraint of milk yield is open to question from the current study and the literature. The antithesis is that milk storage capacity is the major factor involved, especially under ad libitum feeding of high energy diets. This is supported by the low negative energy balance of heifers producing 9000 kg FCM in 305 days, the 17-20% increase in milk yield reported for cows milked 3 times compared with 2 times, per day, without a corresponding significant increase in DMI (Poole, 1982; Amos et al, 1985; De Peters et al, 1985). This is also supported by the non-significant differences in milk yields between diets fed separately and as complete mix, though this resulted in significant difference in DMI (Phipps et al, 1984a). It is possible to argue that both milking routine and limited feed consumption are factors restricting milk secretion. For example, the selection for high milk yields has resulted in trends towards large cows (Broster and Alderman, 1977). Wilson and Wood (1983) gave an average LW of 600 kg for high yielding British Friesians. Langhill cows producing 40 kg milk/day at peak had an average LW of 694 kg whereas heifers producing over 8500 kg FCM in 305 days had a mean LW of

521 kg at calving (Table 8.2). Whether the increase in size is associated with an increase in milk storage capacity that is large udders and/or high feed bulk capacity is not clear. In this study large cows, corrected for parity differences, consumed more DMI but this was not always reflected in correspondingly higher milk yields.

There is the suspicion that body reserves at calving interact with feed intake for the high yielding cow to express its potential for milk production (Hemken, 1971; Bines and Hart, 1982). Due to the inability to quantify accurately body reserves in the live animal, this hypothesis has never been properly tested. In the current study CS (Lowman et al, 1976) was used as an index of body fatness and LWC as an index of body tissue change. Condition score was moderately correlated with body fat ($r = 0.81$, $n = 19$; Appendix Chapter 3, Table A.3.2). The results obtained in this thesis confirm the view therefore that BS is a good tool for dairy cow management (Mulvanny, 1977) but not for estimating body tissue energy for input-output relationships. Ultrasonic measurements of backfat area had the same inherent subjectivity as BS (see Appendix Chapter 3).

Calving BS had a negative association with feed intake, energy balance, LW and BS gain, but a positive correlation with energetic efficiencies in the first 12 weeks of lactation. The results, however, failed to confirm the hypothesis that body fat interacts with feed intake for cows to express milk yield potential. There was no significant interaction between milk yield in lactation week 2 and calving BS on peak or 305-day milk or FCM yields. Also, the results have provided evidence to show that calving BS per se is not an important factor influencing milk yield but it is the ability of the animal to mobilize body fat. This is further illustrated in equations 1-6 of Table 8.3. The results showed that FCM and milk yield are significantly related to LWC

Table 8.3 Equations relating daily milk and FCM yields (kg) to calving condition score (CS, 1-5 units), liveweight change (LWC, kg/day), condition score change (CSC, 1-5 units/day) and DMI (kg) over 2-24 weeks of lactation

1 FCM = $6.0 \pm 27.2 + 1.17 \pm 1.40$ DMI + 1.32 ± 9.89 CS - 0.028 ± 0.508 DMI.CS (R^2 = 20.0%, RSD = 4.63)

2 Milk yield = $6.3 \pm 25.8 + 1.20 \pm 1.33$ DMI + 1.66 ± 9.38 CS - 0.072 ± 0.482 DMI.CS (R^2 = 18.3%, RSD = 4.39)

3 FCM = $4.20 \pm 3.05 + 1.401 \pm 0.160$ DMI*** + 1.426 ± 0.664** LWC - 0.1319 ± 0.0367** DMI.LWC (R^2 = 54.0%, RSD = 3.51)

4 Milk yield = $5.85 \pm 2.98 + 1.279 \pm 0.156$*** DMI + 1.715*** ± 0.648 LWC - 0.1412 ± 0.0359*** DMI.LWC (R^2 = 50.1%, RSD = 3.54)

5 FCM = $7.22 \pm 3.73 + 1.218 \pm 0.194$** DMI + 14.68 ± 6.28**CSC - 0.615 ± 0.324* DMI.CSC (R^2 = 30.4%, RSD = 4.32)

6 Milk yield = $8.79 \pm 3.56 + 1.102 \pm 0.185$*** DMI + 11.87 ± 6.00* CSC - 0.482 ± 0.309* DMI.CSC (R^2 = 27.8%, RSD = 4.12)

7 CSC = $-0.60 \pm 2.40 - 0.050 \pm 1.117$ DMI + 0.91 ± 0.893 CS + 0.0155 ± 0.0435 DMI.CS (R^2 = 9.7%, RSD = 0.495)

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

and BSC. Furthermore, the response of FCM and milk yield to these factors is greater at low post-calving DMI. When the data were further corrected for differences in LW and milk yield in lactation week 2 it was shown (see Chapter 4.1.2) that LW loss was significantly associated with milk fat content. These results are consistent with experimental observations on pre-calving feeding (Grainger et al, 1982; Grainger and McGowan, 1982; Broster and Broster, 1984).

It is important to know if a defined level of body fat reserves is desirable at calving for improved partition of food to milk rather than gain. Growth hormone, which has a lipolitic effect, is known to be slightly higher in cows on a high plane of nutrition pre-partum than those on a low plane of nutrition (Kunz et al, 1985). Moreover, exogenous growth hormones given to lactating cows resulted in an increased partition of feed into milk rather than to body gain (Bauman et al, 1985). Also, Grainger et al (1982) came to the conclusion that thin cows tend to partition more of their feed early in lactation into gain rather than milk compared to fat cows. Cows calving between BS 2.0-3.0 were observed (Appendix Chapter 4.2.2) to partition more feed into milk than cows calving in BS 3.0-3.5 in lactation weeks 19-24. It is, however, difficult to understand the causes of the discrepancies between the two experiments because condition scoring was on different scales, and also the animals were given restricted levels of feed rather than ad libitum. It is, however, significant to note that Garnsworthy and Topps (1982b) observed both higher milk yields and BS gain of thin (1.5-2.0 units BS) animals than fat animals (2.5-4.5 units BS). Also, Broster et al (1985) noted that cows underfed in two consecutive lactations have a change in partition of food towards gain rather than milk. These results and the literature suggest that calving BS between 1.5 and 2.0 has no detrimental effect on feed partition for milk production

when cows were subsequently fed on ad libitum diets.

Other interesting results not previously reported in the literature but obtained in the current study were:

(a) The interaction of milk yield in lactation week 2 and calving BS on DMI and nutrient utilization traits. Further, an interpretive model is provided below for the hypothesis that body reserves at calving are a major component of energy requirements. This is based on the premise that in the wild during evolution, where feed resources fluctuated between scarcity and plenty, animals survived by alternately storing and mobilizing body fat. The innate capacity for storage and mobilization has not disappeared even after many generations of selection.

(b) Heifers were not different from cows in their response to increased calving BS on DMI, nutrient utilization and milk yield as might be expected due to their additional requirements for growth. This is, however, not conclusive, due to the narrow range of BS used (CV = 10.5%) and also the small proportion of cows in this Trial(2).

(c) The minimum BS level below which cows did not catabolise body fat was 1.5 (Figure 8.5). Fat cows generally lost the most condition but were still fatter at the end of the experiment than thin cows. Also, fat animals lost more BS in relation to calving BS than thin animals, suggesting that the amount of body fat loss is not directly proportional to calving body fatness. When BS loss during lactation was scaled by calving BS (BSCR) and regressed on calving BS, the following equation was obtained for cows.

$$BSCR = 0.2102 \pm 0.0351 - 0.1144^{**} \pm 0.00112\ BS$$

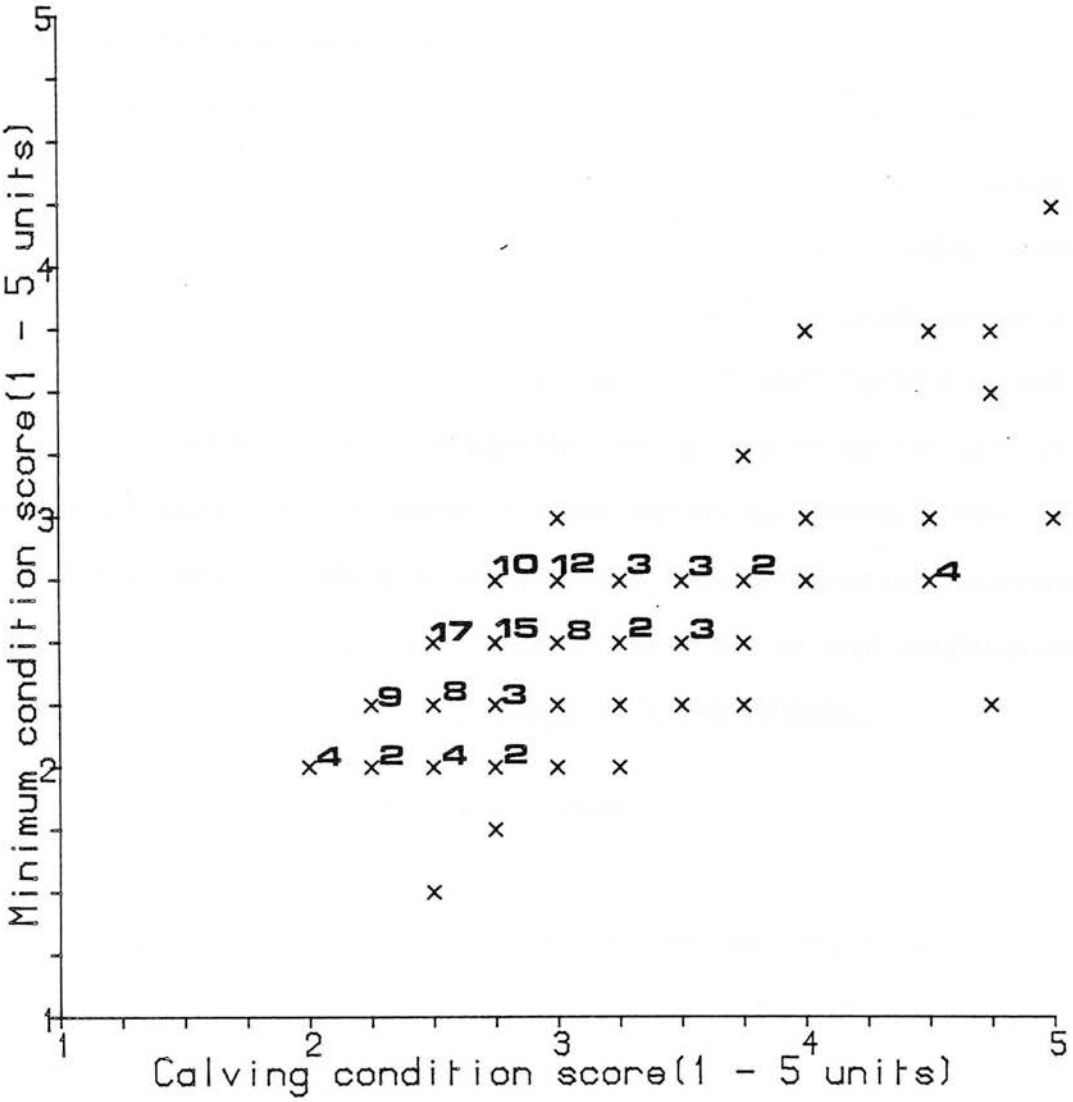
$$R^2 = 45.2,\ RSD = 0.106$$

There was no similar significant relationship for heifers. The correlation of calving BS on BSCR and BS loss were -0.023 and 0.063 respectively.

The problem of finding an accurate estimate of body tissue change in the live animal has proved intractable (Moe, Tyrell and Flatt, 1971). LWC is easy to measure but is affected not only by gut fill, but also the replacement of fat by water during body weight changes (Chigaru and Topps, 1981). It is therefore doubtful if empty body weight change would have conferred any advantage to LWC by using the ARC (1980) multiplier of 1.09 for conversion of empty LW gain to LW gain (Alderman et al, 1982). The small variation in the regression coefficients of energy balance on LWC in different stages of lactation for Trial 2 suggest that lipid-free LWC would be less variable and be more useful as an index of body tissue change. In fact, the constancy of lipid-free LWC is the basis for estimation of body composition of cattle using body water techniques (Reid et al, 1968; Wright, 1982). Evidence indicating some protein loss in early lactation in dairy cattle (Belyea et al, 1978; Botts et al, 1979), however, suggests that lipid-free LWC may also not be constant enough to be of practical use.

The available information indicates that housed dairy cattle spend 3.0-4.5 h per 24 h eating (Vasilatos and Wangsness, 1980; Harb and Campling, 1983; Tanida et al, 1984). The results in this thesis showed that time spent eating was strongly and positively correlated with dry matter intake. VFI could be improved therefore by reducing time spent on non-eating activities such as by providing fresh feed or turning the feed in the troughs during low eating activity periods (Baile and Forbes, 1974). It is, however, doubtful from the available evidence provided in the thesis and the literature (Tanida et al, 1984) if non-eating activities are amenable to change. There is lack of information and thus understanding of the mechanisms governing hunger and satiety mechanisms in dairy cattle. Future success in the use of feeding behaviour to design management strategy to improve the VFI of dairy cattle will depend

Figure 8.5 : Relationship between calving condition score and minimum condition score during lactation for cows



on information on the physiological mechanisms governing meal eating patterns of dairy cattle.

8.1 Interpretive Models

8.1.1 STATE CHANGE

According to two physiological mechanisms:

(1) homeostasis (maintenance of physiological equilibrium), and

(2) homeorhesis (co-ordination of metabolism of various tissues to support a physiological state),

body nutrients are partitioned preferentially first for maintenance of essential body functions, then for mammary gland requirements and, lastly, body gain (Bauman and Currie, 1980). Assuming these basic hypotheses, it is interesting to speculate about the physiological or metabolic status of the high yielding dairy cow in early lactation. Most workers subscribe to the view that the cow, because of limited appetite mobilizes stored body reserves to meet her energy deficit. From the present results an antithesis is proposed; that the cow stores body reserves during the dry period and uses these in preference to feed consumption in early lactation, even under ad libitum feeding conditions.

This antithesis can be interpreted as follows.

The animal has:

(1) A set point beyond which it will not mobilize body tissues (at this point homeostatic mechanisms supercede homeorhetic mechanism - see Broster et al, 1985).

(2) The set point is related to the amount of body fatness, that is the higher the fat reserves, the higher the mobilizable body reserves

and set point. Fat animals will therefore mobilize more body reserves leading to more LW or BS loss but will still be fatter than thin cows (see Figure 8.5). The regression of minimum BS levels, reached during lactation, on calving BS (CS) was

$$BS = 1.238 \pm 0.115 + 0.4362^{***} \pm 0.0366\ CS$$

$$R^2 = 53.0,\ RSD = 0.29$$

Thus above BS 1.24 there is a 56% BS loss per unit calving BS during lactation.

Thresholds for body fat content have been observed in non-ruminants, such as the rat, but not thus far in ruminants (Weston, 1982). There appears, however, to be no reason why a similar effect cannot be postulated for dairy cows. A changing set point with changing body fatness is possible due to adaptive or maladative physiological influences (Booth, 1979). Furthermore, as suggested by Baumgart (1970), animals which fatten have higher set points and thus eat more because a higher feedback signal is necessary to balance the higher set points.

8.1.2 MILK YIELD x CALVING CONDITION SCORE INTERACTION ON DMI

This interpretation is based on the following assumptions:

(1) Energy flow from catabolizable body fat is compared with energy requirements and any deficit in requirements is then met by the animal consuming an equal amount of energy from the feed.

(2) The rate at which nutrients are catabolized from the body is similar for all cows, but is dependent on level of body fatness.

Given these assumptions, it is possible to compare two cows A and B with the same high calving BS. A is intrinsically low yielding (L, < 25 kg/day

milk in lactation week 2) and B is high yielding (H, above 30 kg/day milk in lactation week 2).

ME requirement for maintenance and production:

For A = Y MJ/day

and B = X MJ/day

Amount of catabolizable energy in body

= n MJ ME

Rate of mobilization of body energy per unit catabolizable body energy

= r MJ per MJ day

Energy mobilized per day (E, MJ)

= n x r

Energy required from the diet:

Cow A = Y-E

Cow B = X-E

Since B has a greater demand for energy than A there is more dilution of mobilizable energy, that is $^{E}/_{X-E}$ is less than $^{E}/_{Y-E}$. This means that the amount of catabolizable energy from body fat will have more influence on the feed intake of cow A than cow B. This also means that cow A will be more energetically efficient than cow B, but its energy balance should be similar at similar LW.

While the model is satisfactory in interpreting this interaction of milk yield and calving BS on DMI and energetic efficiency, it cannot explain the interaction on energy balance. Probably errors in the physiological mechanisms have resulted in the low yielding cow having a higher rate of body fat catabolism than the high yielding cow. This is demonstrated in Table 8.4 for two selected cows numbered 96 and 189. The rate of BS loss and negative energy balance was higher in the low yielding cow than

the high yielding. This could also be due to errors in estimation of differences in body fat from an insensitive measure such as body condition scoring.

Table 8.4 Differences between high (H) and low (L) yielding cows of the same calving BS in feed intake and production in lactation weeks 2-6

	Cow number	
Variable	**96(H)**	**189(L)**
Milk yield (lactation week 2, kg/day)	36.9	24.7
FCM (kg/day)	39.9	31.0
ME intake (MJ/day)	228	148
Energy balance (MJ/ME/day)	-45.5	-65.3
Gross efficiency (%)	54.3	63.7
Net efficiency (%)	77.5	103.9
Calving condition score (1-5 units)	5.0	5.0
Calving liveweight (kg)	875	760
Calving backfat area (cm^2)	11.5	9.0
Condition score loss (1-5 units)*	1.0	1.5
Backfat area loss (cm^2)*	4.8	1.5
Liveweight change (kg)*	-40	-120

* From weeks 0-6 of lactation

These results and intpretations fit the following simple broader model for animals assumed to be in a non-limiting environment.

Milk yield potential is set at calving by inherited milk secretion ability. This then sets the potential daily feed intake (P) of the animal during lactation. The actual daily intake (I) is dependent on the amount of catabolizable body energy reserves (n) and the daily rate of mobilization of body energy reserves (r). Thus energy mobilized per day E (n x r) is compared with potential milk yield energy requirements and the animal eats I = P-E. Thus body fat or tissue changes will depend on the level of

body fatness at calving.

Monteiro (1972) used delayed parameters whereas Forbes (1977, 1983) used physical restrictions of the gut to account for this effect of body tissue mobilization. This model assumed that the lag between feed intake and production requirements is dependent on n and r. From the present results r can be calculated from daily energy balance and calving BS as:

$$\text{Energy balance (MJ ME)} = 23.7 \pm 12.9 - 15.63^{**} \pm 4.07 \text{ BS}$$

$$R^2 = 10.5, \quad RSD = 33.3$$

Week of zero energy balance can be calculated from week of minimum BS change during lactation and calving BS as:

$$\text{Week} = -6.13 \pm 1.70 + 4.17^{***} \pm 0.543 \text{ BS}$$

$$R^2 = 31.7, \quad RSD = 4.4$$

Potential daily DMI can be calculated from maximum DMI and daily milk in lactation week 2 (MY) - kg as:

$$P(kg) = 16.40 \pm 1.28 + 0.1895^{**} \pm 0.0409 \text{ MY}$$

$$R^2 = 14.1, \quad RSD = 2.31$$

The regulation of change of state may be more complex than this simple model, at least for animals calving at BS 2-5. For, at similar calving BS, high yielding cows lost more BS than low yielding cows (see equation below). Also, it is possible that n x r declines in an exponential manner as LW during lactation (Wood et al, 1980).

$$\text{BS loss} = -1.73 \pm 0.174 + 0.5370 \pm 0.0358^{**} \text{ BS} + 0.01811^{***} \pm 0.000513 \text{ MY}$$

$$R^2 = 68.3, \quad RSD = 0.283$$

Probably homeostatic mechanisms are more predominant in low yielding cows resulting in less negative state change. Whereas homeorhetic mechanisms are more predominant in high yielding cows resulting in more negative state change (Blake and Custodio, 1984).

This interpretive model generally supports hypothesis 2 of Whittemore (1981) that under conditions of non-limiting resources inherited milk secretion ability is a controlling factor in milk yield.

8.2 Concluding remarks

8.2.1 PREDICTION OF VFI - PRACTICAL RELEVANCE

From past experimental evidences, it is known that multiple regression methods are not very accurate for predicting VFI (Baile and Della-Ferra, 1981). Moreover, most equations established by this method have been retrospective rather than predictive. Nevertheless, for farm management purposes simple predictive equations are necessary. In this thesis an attempt was made to establish the predictive value of animal characteristics immediately post-partum on VFI and also nutrient utilization for milk production. Also to establish some of the causes of the apparent poor predictive value of these equations.

The results showed that until errors in measurements and thus the quantification of the true value of animal characteristics are clearly defined, even in combination, these factors will be of poor predictive value for VFI and nutrient utilization traits. Also, predictions must take account of differences between stages of lactation.

Management of cows to calve at BS 2.0-3.0 can prevent problems of low feed intake in early lactation and probably cases of metabolic diseases as acetonaemia. This will have no adverse effect on milk yield, for it could not be shown that body fatness between calving BS 2.0-5.0 interacts with DMI for high milk production. Furthermore, high calving BS has adverse effects on milk protein content. An improvement in accuracy of condition

scoring in relation to body composition is needed to be able to estimate input-output relationships more accurately and thus quantify the benefit, if any, of different levels of body fatness.

The need for a precise estimate of body tissue energy loss or LWC in the live animal still remains to be quantified. LWC proved useful in the explanation of the effects of calving BS on milk yield but proved inadequate for predictive purposes for VFI and nutrient utilization traits. The use of lipid-free LWC may prove useful in future, but research work to quantify this is needed.

Selection of animals for high milk yield results in animals with high appetites and milk production efficiency; and the ability to mobilize body reserves and probably also store body reserves later in lactation.

Selection of animals for large size within the same age group will result in increased feed intake in early lactation, but not necessarily milk production.

Differences between animals in energetic efficiency for milk production are due to variation in the mobilization and storage of body reserves.

Fifty per cent of the within day variation between animals in VFI is due to time spent eating. The chances of manipulating animals to permit them to spend more time eating does not, however, appear encouraging for animals fed ad libitum.

8.2.2 PROPOSALS FOR FURTHER RESEARCH

The experiment has posed the following unanswered questions and thus important areas of future research:

(1) Whether milk yield or body fatness drive the animal into negative energy balance in early lactation or whether the relationship is synergistic as suggested in this thesis. The use of a range of animals including those thinner than those used in this work might provide the answer.

(2) Whether energy reserves are there to be used in preference to food consumption. This could be tested by feeding animals protected sources of carbohydrate energy labelled with carbon-14.

(3) Whether limiting nutrient resource requirements are similar for animals of variable BS at calving. This can be tested by feeding diets of different energy:protein ratios to animals of different condition.

(4) What the physiological mechanisms are, which cause differences between low and high yielding cows in their response in VFI due to increased BS at calving.

(5) Whether there is any genetic relationship among components of milk yield and tissue energy balance. What are the limits of total tissue reserve and rate of catabolism of tissues to sustain milk yield? Whether normal circulating levels of lipolytic hormones (growth hormones) and lipogenic hormones (insulin) can be used in an index in the selection of animals for high milk yields with little use of body reserves.

(6) Whether there is a genetic component which affects appetite, irrespective of milk production level, LW and BS.

(7) What the relationship between LW and economic efficiency is, since increasing LW within the same parity under ad libitum feeding is biologically less efficient. In this context, it must be remembered that large animals may have greater meat value at culling and probably have

large fast growing calves.

(8) What the reaction of housed dairy cattle to a voluntary choice between outside environment and eating over 24 h daily periods and at different stages of lactation would be. The experimental design must contain both a control and a treatment group.